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Upper Spokane River Model: Model Calibration, 2001

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Upper Spokane River Model: Model Calibration, 2001

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Technical Report EWR-1-03

Prepared for the City of Spokane
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Acknowledgements

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Introduction

The Upper Spokane River system under consideration is located in the Northeastern part of Washington State and runs from the Stateline with Idaho, River mile (RM) 96.0, downstream to Long Lake dam at RM 32.5. Figure 1 shows the river system and an outline the boundaries of the City of Spokane.

The Washington Department of Ecology (Ecology) is interested in a water quality model for the Upper Spokane River system for use in developing Total Maximum Daily Loads (TMDLs). As a result, Ecology and the Corps of Engineers funded a study to develop a water quality and hydrodynamic model of the Spokane River system for the years 1991 and 2000. Since the City of Spokane and other point dischargers to the Spokane River have taken considerable field data in the Spokane River system during 2001, the City of Spokane funded this study primarily to:

- Continue the development of the Spokane River model for the year 2001, and
- Ensure that the model retains its calibration for the year 2001

A hydrodynamic and water quality model, CE-QUAL-W2 Version 3 (Wells, 1997), was applied to the Spokane River system for the years 1991 and 2000. CE-QUAL-W2 is a two dimensional (longitudinal-vertical), laterally averaged, hydrodynamic and water quality model that has been under development by the Corps of Engineers Waterways Experiments Station (Cole and Wells, 2000).

Prior reports prepared for the Spokane River modeling study include:

- Annear et al. (2001) - Upper Spokane River Model: Boundary Conditions and Model Setup for 1991 and 2000
- Berger et al. (2002) - Upper Spokane River Model: Calibration for 1991 and 2000
- Slominski et al. (2002) - Upper Spokane River Model: Boundary Conditions and Model Setup for 2001 where information such as the following were detailed:
    1. Inflows, temperatures, and water quality
    2. Meteorological conditions
    3. Bathymetry of the Spokane River and Long Lake and the model grid
    4. Reservoir operations and structure information

This report evaluates the 2001 model calibration and discusses issues relative to that calibration effort. The calibration effort focused on model predictions of hydrodynamics (flow and water level), temperature, and eutrophication model parameters (such as nutrients, algae, dissolved oxygen, organic matter, coliform). The model calibration period was from March 15, 2001 to October 31, 2001.

This information is divided into the following sections in this report:

- Hydrodynamic Calibration
- Temperature Calibration
- Water Quality Calibration
- Summary and Conclusions

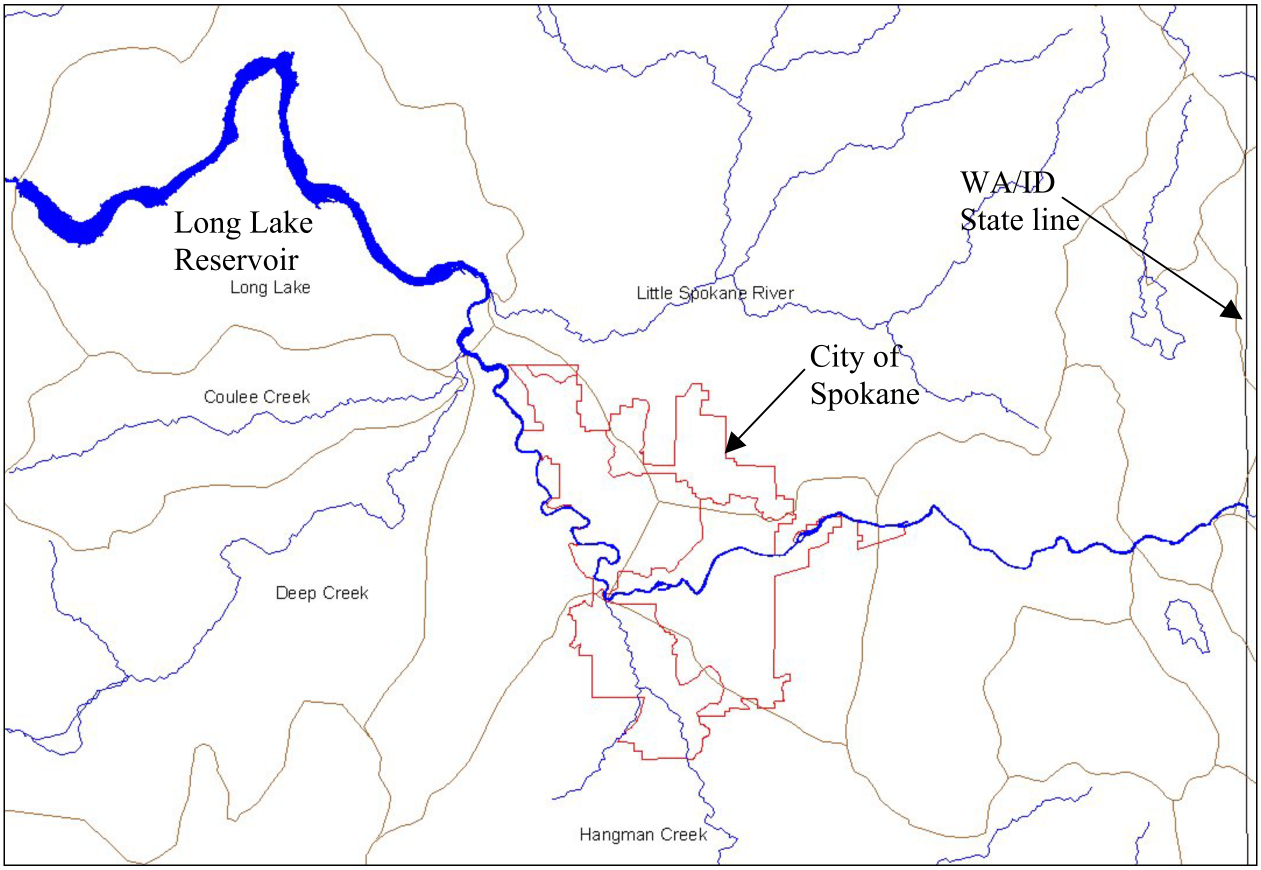

Figure 1. Model domain, WA-ID state line to Long Lake reservoir

Monitoring Sites

The monitoring sites utilized in the development and calibration of the Spokane River model consist of monitoring sites along the Spokane River and tributaries and point discharges to the river. Data at these sites consist of water level, flow, temperature, and water quality.

There are several water level and flow gage stations along the Spokane River. Figure 2 shows a map of the model domain with several key water level and flow gage stations. Table 1 provides a list of the USGS gage stations.

Table 1. U.S. Geological Survey gage stations

Gage ID	Description	RM
USGS12419000	SPOKANE RIVER NR POST FALLS, ID	100.9
USGS12419500	Spokane R Above Liberty Br Nr Otis Orchard, Wash (Harvard Rd)	93.8
USGS12420500	SPOKANE RIVER AT GREENACRES, WA (Barker Rd)	90.3
USGS12422500	SPOKANE RIVER AT SPOKANE, WA	72.9
USGS12424000	HANGMAN CREEK AT SPOKANE, WA	72.3
USGS12431000	LITTLE SPOKANE RIVER AT DARTFORD, WA	56.9
USGS12433000	SPOKANE RIVER AT LONG LAKE, WA	32.1

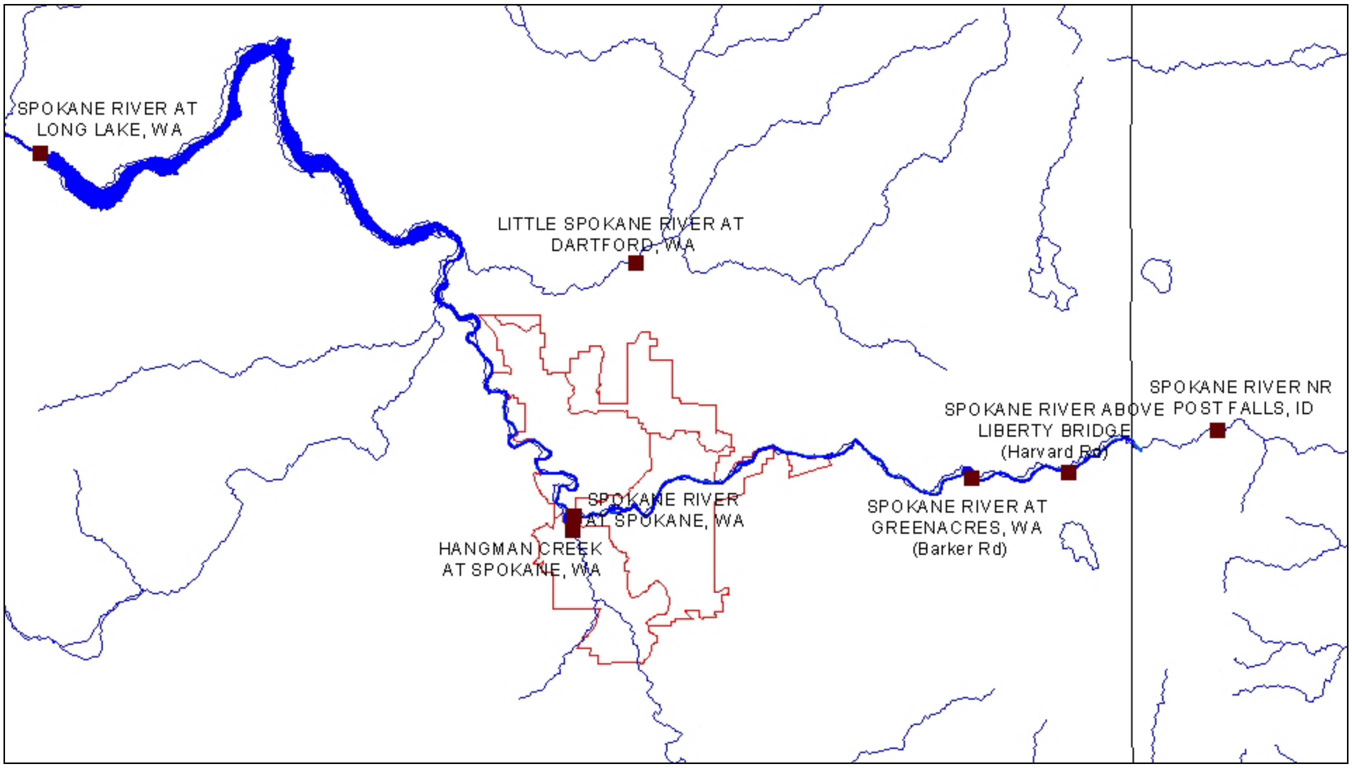

Figure 2. U.S. Geological Survey gage stations along the Spokane River

Water quality data were provided by the Washington State Department of Ecology (DOE), the dischargers, Avista Corporation, and Spokane County. Additional flow, temperature and water quality data were provided by the USGS in WA and ID. The data were collected from January 2001 through December 2001. Figure 3 shows a map of the upper Spokane River region with the water quality monitoring sites. Figure 4 shows the water quality sites in Long Lake. Monitoring sites in the Spokane River just above Nine Mile dam to the Upper Falls dam are shown in Figure 5. Spokane River monitoring sites just below and above the Upriver dam facilities are shown in Figure 6. Figure 7 shows the remaining monitoring sites above Upriver dam to the state line with Idaho. Table 2 lists the water quality monitoring sites with their associated river mile.

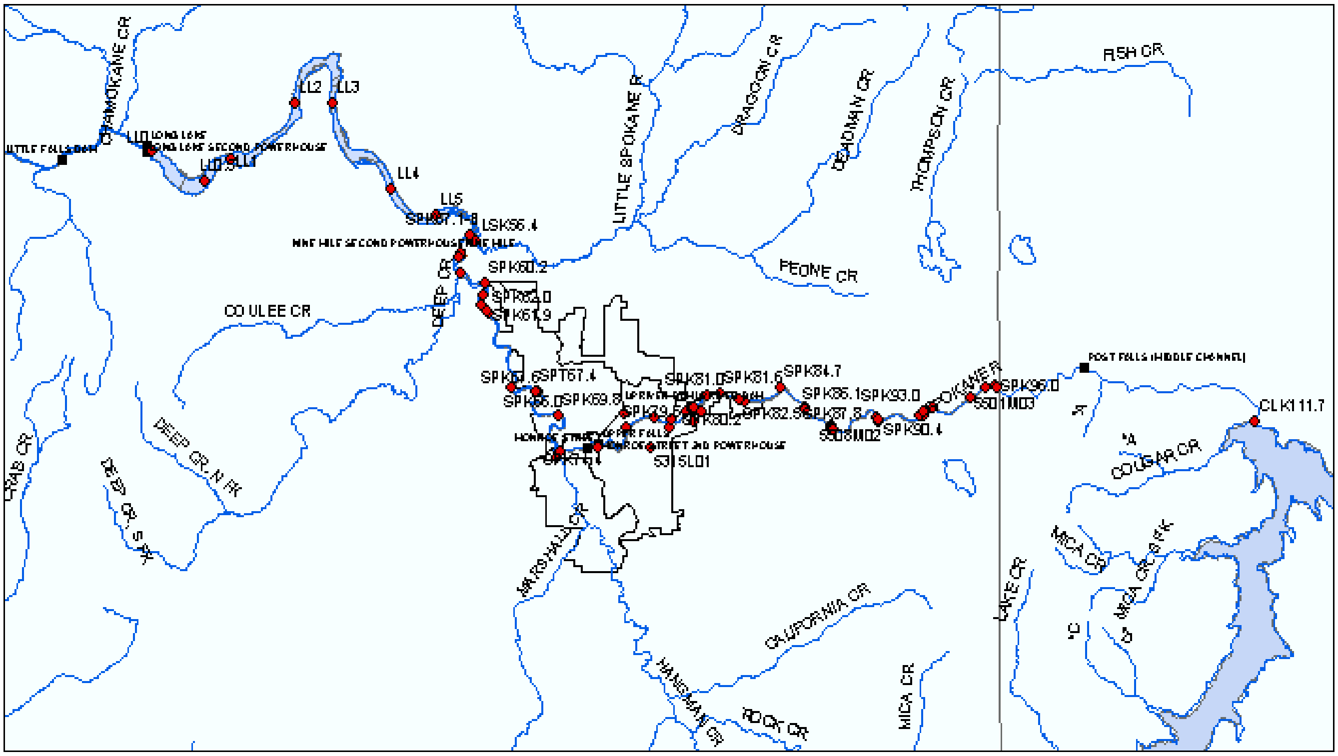

Figure 3. Water quality monitoring sites along the Spokane River and Long Lake reservoir

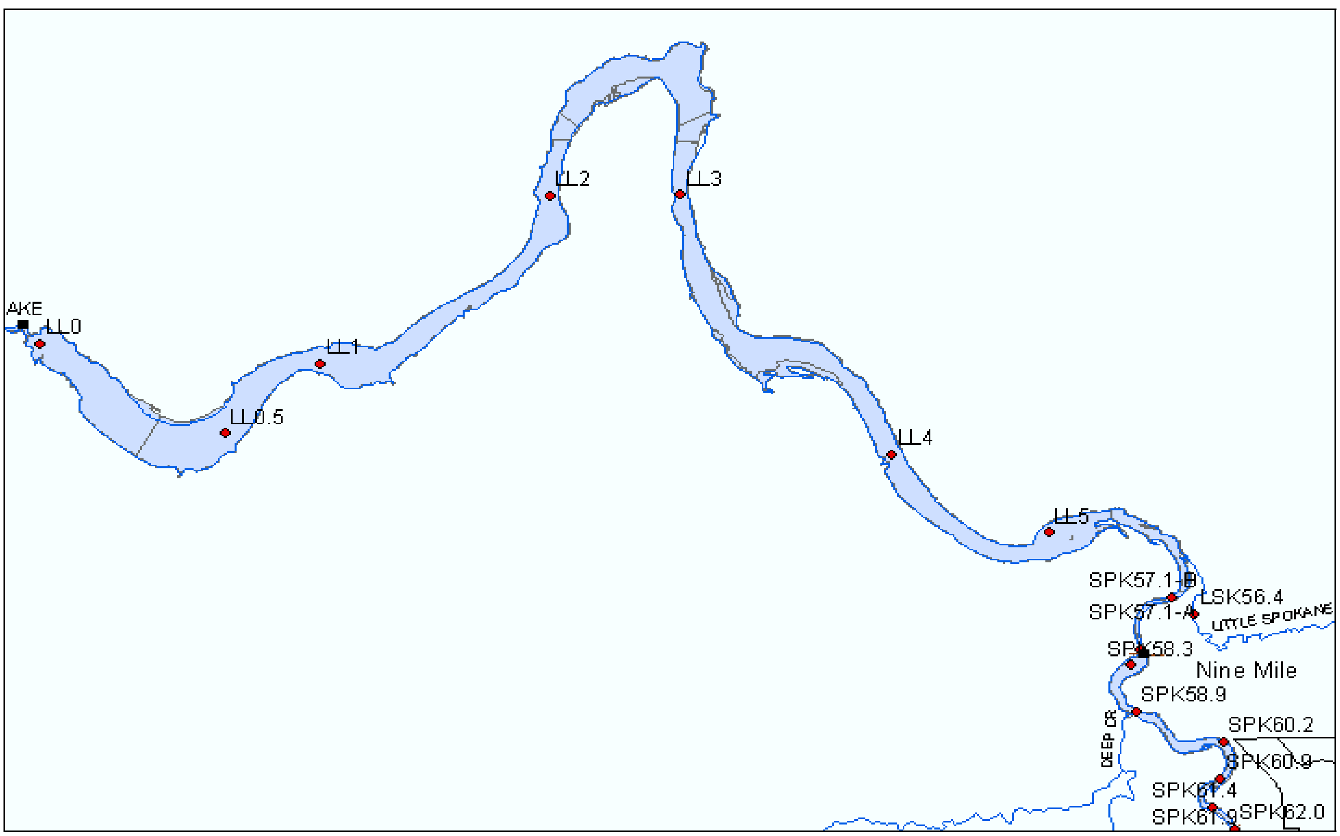

Figure 4. Water quality monitoring sites in Long Lake Reservoir

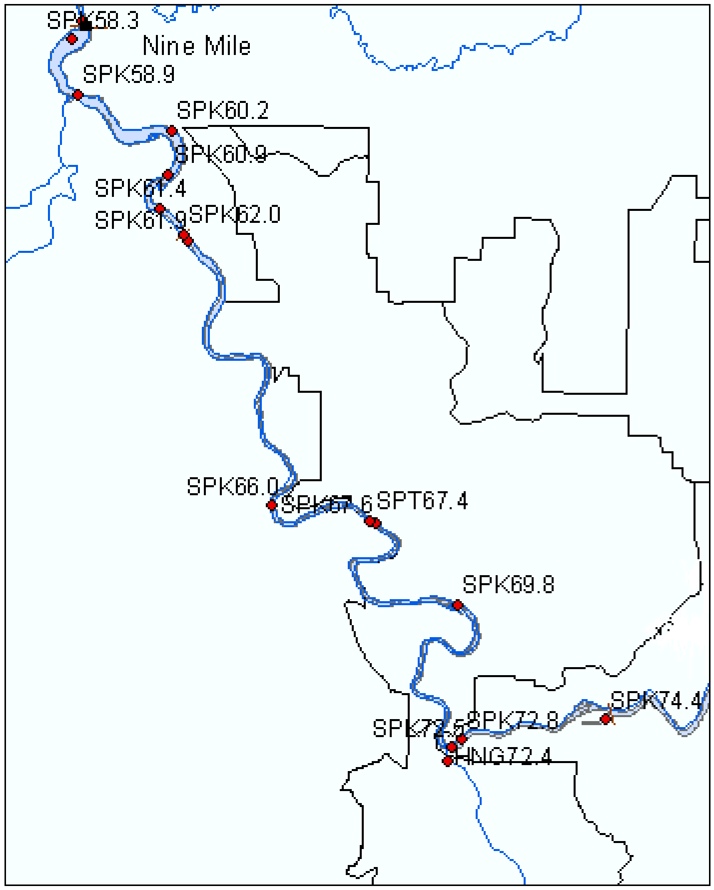

Figure 5. Water quality monitoring sites along Nine Mile Reservoir

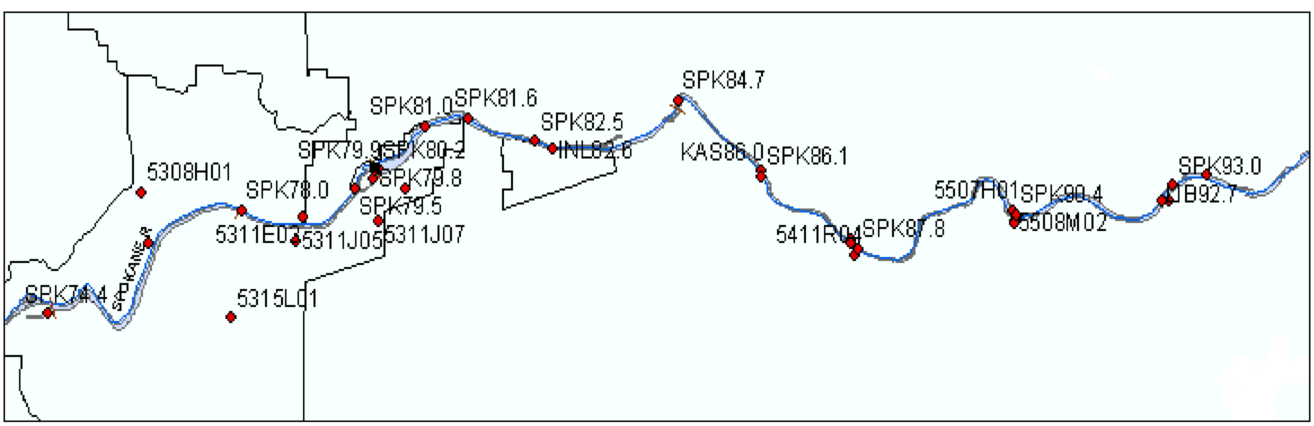

Figure 6. Water quality monitoring sites along the Spokane River near Upriver Dam (includes both surface water and well monitoring sites)

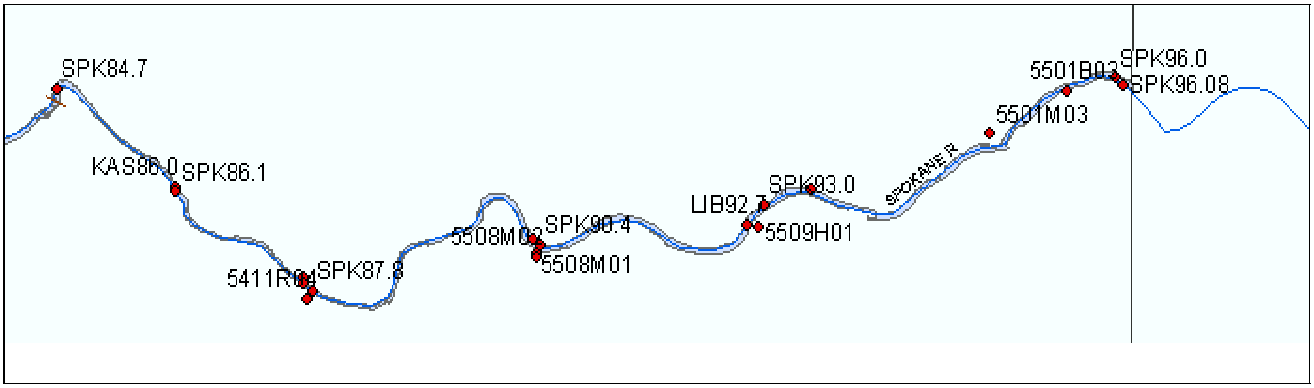

Figure 7. Water quality monitoring sites near the WA-ID state line (includes both surface water and well monitoring sites)

Table 2. Water Quality Monitoring sites		
Site ID	**Description**	**RM**
USGS12419000	Spokane River at Post Falls, ID	100.52
LL0	Long Lake @ Station 0 (near dam)	32.66
LL0.5	Long Lake @ Station 0.5	35.90
LL1	Long Lake @ Station 1	37.62
LL2	Long Lake @ Station 2	42.06
LL3	Long Lake @ Station 3	46.42
LL4	Long Lake @ Station 4	51.47
LL5	Long Lake @ Station 5	54.20
LSK56.4	Little Spokane River @ Long Lake (near mouth): near HWY 291 Bridge.	56.40
SPK57.1-A	Spokane River at Long Lake: @ 1 mile downstream of Nine Mile Dam.	57.10
SPK57.1-B	Spokane River at Long Lake: @ 1 mile downstream of Nine Mile Dam.	57.10
SPK57.74	Spokane River Below 9 Mile Dam, Spokane River at 9 mile bridge	57.74
SPK58.1	Downstream of Nine Mile Dam at Charles Road bridge	58.10
SPK58.3	Spokane River above Nine mile Dam: 0.2 miles upstream of Nine Mile Dam.	58.30
SPK58.9	Spokane River above Nine mile Dam: 0.8 miles upstream of Nine Mile Dam.	58.90
SPK60.2	Spokane River above Nine mile Dam: 2.1 miles upstream of Nine Mile Dam.	60.20
SPK60.9	Spokane River above Nine mile Dam: 2.8 miles upstream of Nine Mile Dam.	60.90
SPK61.4	Spokane River above Nine mile Dam: 3.3 miles upstream of Nine Mile Dam.	61.40
SPK61.9	Spokane River above Nine mile Dam: 3.8 miles upstream of Nine Mile Dam.	61.90
SPK62.0	Spokane River at Seven Mile Bridge	62.00
SPK66.0	Spokane River at Riverside State Park, at Bowl and Pitcher	66.00
SPT67.4	Spokane River AWTP effluent discharge	67.40
SPK67.6	Spokane R Upstream (above) Spokane AWTP	67.60
SPK69.8	Spokane River at Fort Wright Bridge	69.80
SPK69.8?	Spokane River at TJ Meenach	69.80
HNG72.4	Hangman Creek at mouth, upstream of confluence with the Spokane River	72.40
SPK72.5	Spokane River Upstream of Hangman Cr.	72.50
SPK72.8	Spokane River, 200 m downstream of Spokane River gage station	72.80
SPK73.4	Spokane River at Monroe Street Powerhouse, Post St. Bridge	73.40
SPK74.4	Spokane River at Walkbridge behind Spokane Center	74.40
SPK74.8	Spokane River at Division St Bridge	74.80
5315L01	Olive & Fiske monitoring well, NW corner Fiske & Olive	76.34
SPK76.5	Spokane River at Mission Street Bridge, 76.5	76.79

Table 2. Water Quality Monitoring sites		
Site ID	**Description**	**RM**
5309M04	Avista monitoring well near SE corner of Main Office, Avista MW4	76.87
5308H01	Denver & Marietta, City monitoring well	77.12
SPK78.0	Spokane River at Green St. Bridge	78.12
5310R01	GE MW-22	78.86
5311E03	Avista Beacon Substation 208 well	78.95
SPK79.5	Downstream of Upriver Dam Powerhouse	79.50
5311J07	Hale's Ale Nested Site, middle	79.65
5311J05	Hale's Ale Nested Site, east	79.65
SPK79.7	Spokane River at Upriver Dam, downstream, 79.5	79.78
SPK79.8	Spokane R Upstream Upriver Dam Powerhouse, Dam Forebay	79.86
SPK79.9	Spokane River above Upriver Dam: 0.1 miles upstream of Upriver Dam	79.90
SPK80.2	Spokane River above Upriver Dam: 0.4 miles upstream of Upriver Dam	80.20
5312C01	Felts Field City monitoring well	80.41
SPK81.0	Spokane River above Upriver Dam: 1.2 miles upstream of Upriver Dam	81.00
SPK81.6	Spokane River above Upriver Dam: 1.8 miles upstream of Upriver Dam	81.60
SPK82.5	Spokane River above Upriver Dam: 2.7 miles upstream of Upriver Dam	82.50
INL82.6	Inland Empire Paper Co discharge, IWTP	82.60
SPK84.7	Spokane River at Plantes Ferry Park Foot Bridge	84.70
KAS86.0	Kaiser Aluminum IWTP	86.00
SPK86.1	Spokane River Upstream Kaiser IWTP	86.10
5411R02	Sullivan Road and Centennial Trail, monitoring well, Spokane R @ Sullivan Rd, 200 ft N, SW corner Sullivan Park lower parking lot	87.44
5411R03	Sullivan Park North, monitoring well, Spokane R. @ Sullivan Rd, 100 ft N, Sullivan Park near bluff over river	87.46
5411R04	Sullivan Park South, monitoring well, Spokane R. @ Sullivan Rd, 100 ft S, County Row, W of Sullivan, S. of Trail	87.59
SPK87.8	Spokane River at Sullivan Rd. Bridge	87.80
5507H01	Barker Road north of river, monitoring well, Spokane R. @ Barker Rd, 100 ft N, W of Barker, N of River	90.24
5508M01	Barker Road Centennial Trail North, monitoring well, Spokane R. @ Barker Rd, 100 ft S, Barker Rd Cent Trail parking lot #1	90.34
5508M02	Barker Road Centennial Trail South, monitoring well, Spokane R. @ Barker Rd, 200 ft S, SW corner Cent Trail parking lot, Barker Rd	90.35
SPK90.4	Spokane River at Barker Rd. Bridge	90.40
5509H01	Monitoring well, USGS Well 5	92.42
LIB92.7	Liberty Lake POTW	92.70
SPK93.0	Spokane River at Harvard Rd. Bridge	93.00
5510C03	Monitoring well, USGS Well 18	93.06
5501M03	Monitoring well, USGS Well 10	94.94
5501B03	Monitoring well, USGS Well 3	95.75
SPK96.0	Spokane River at the Stateline Bridge, 400 ft upstream of Stateline Bridge.	96.00
SPK96.08	Spokane River near the Stateline	96.10

There were four significant point sources along the Spokane River that were included in the modeling effort. The sites are listed in Table 3 along with their river mile location. Figure 8 shows the location of the four dischargers along the river. The data were obtained from the National Pollutant Discharge Elimination System (NPDES) through the WA Department of Ecology and additional data were obtained either directly from the dischargers or from WA Department of Ecology, which acquired the data from the dischargers. Each point source is characterized by flow, temperature, and additional water quality constituent concentrations.

Table 3. Point Source dischargers considered in the model

Discharger Description	RM	Model Segment
Liberty Lake WWTP	92.7	18
Kaiser Aluminum	86.0	43
Inland Empire Paper Co	82.6	56
Spokane River WWTP	67.4	115

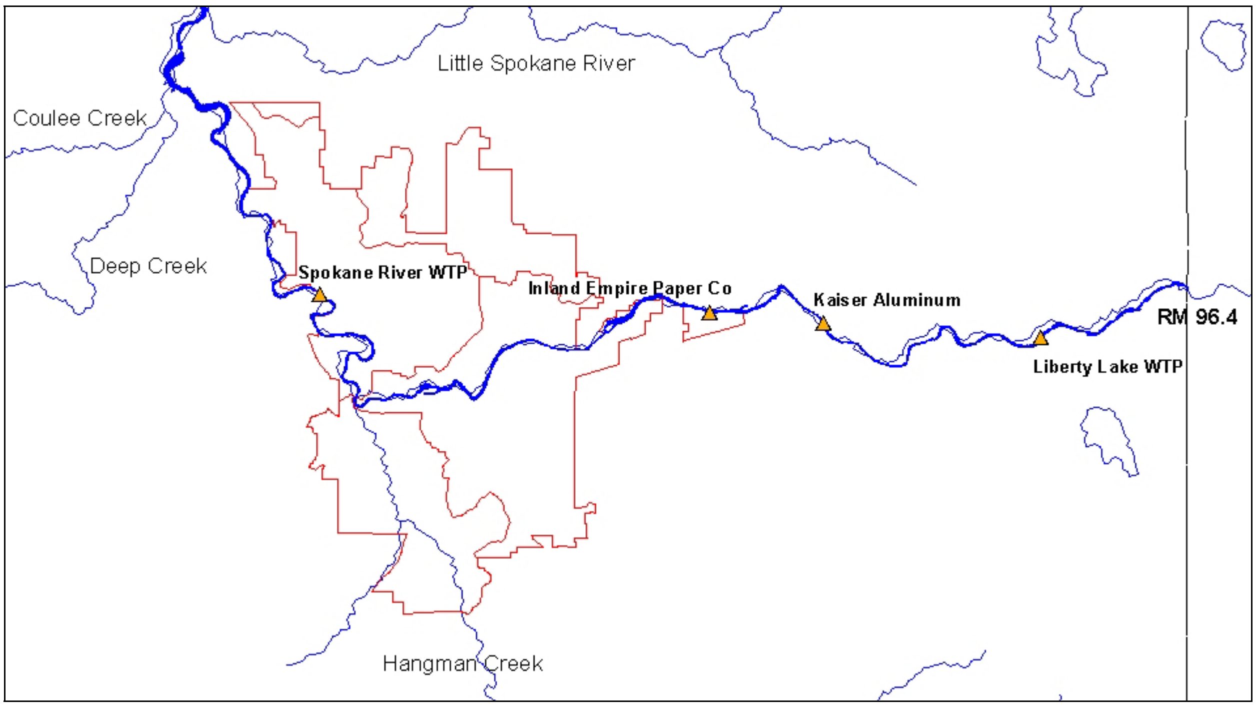

Figure 8. Point Discharges to the Spokane River

Hydrodynamic Calibration

Upriver Reservoir

The hydrodynamic calibration of the Upper Spokane River system was started at the furthest upstream location as the water balance results affect the downstream water balance. The Upriver reservoir is located at approximately RM 80 and consists of a dam that operates as a “run-of-the-river” facility. Water level data were compared with model results for 2001 as shown in Figure 9. Table 4 shows water level statistics for 2001.

Table 4. Water level error statistics for Upriver Reservoir, 2001.

Year	n, # of data comparisons	Water level model –data error statistics	
		AME, m	RMS error, m
2001	230	0.086	0.100

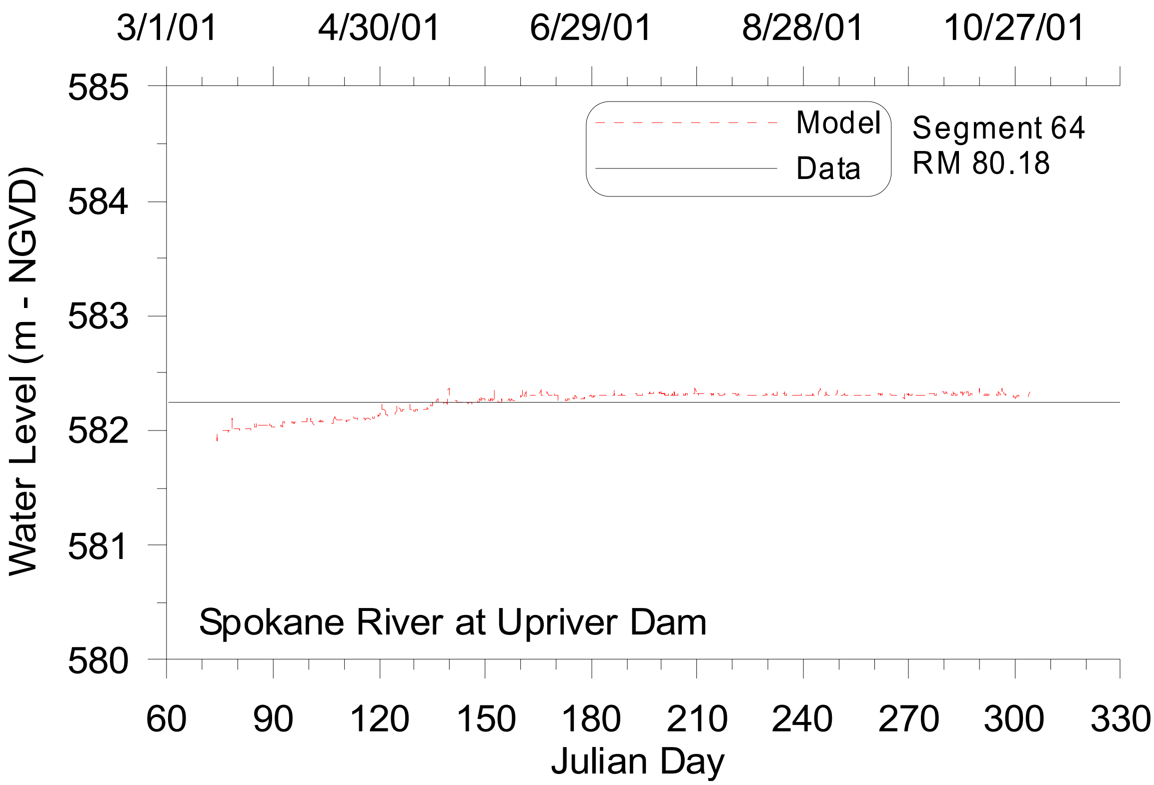

Figure 9. Water level prediction compared with data for the Spokane River at Upriver Dam.

Upper Falls Reservoir

The hydrodynamic calibration for the Upper Falls Reservoir was conducted after the Upriver Reservoir water balance. The Upper Falls Reservoir Dam is located at approximately RM 75 and is operated as a "run-of-the-river" facility. Water level data were compared with model results for 2001 as shown in Figure 10. Table 5 shows water level statistics for 2001.

Table 5. Water level error statistics for Upper Fall Reservoir, 2001.

Year	N, # of data comparisons	Water level model –data error statistics	
		AME, m	RMS error, m
2001	230	0.074	0.086

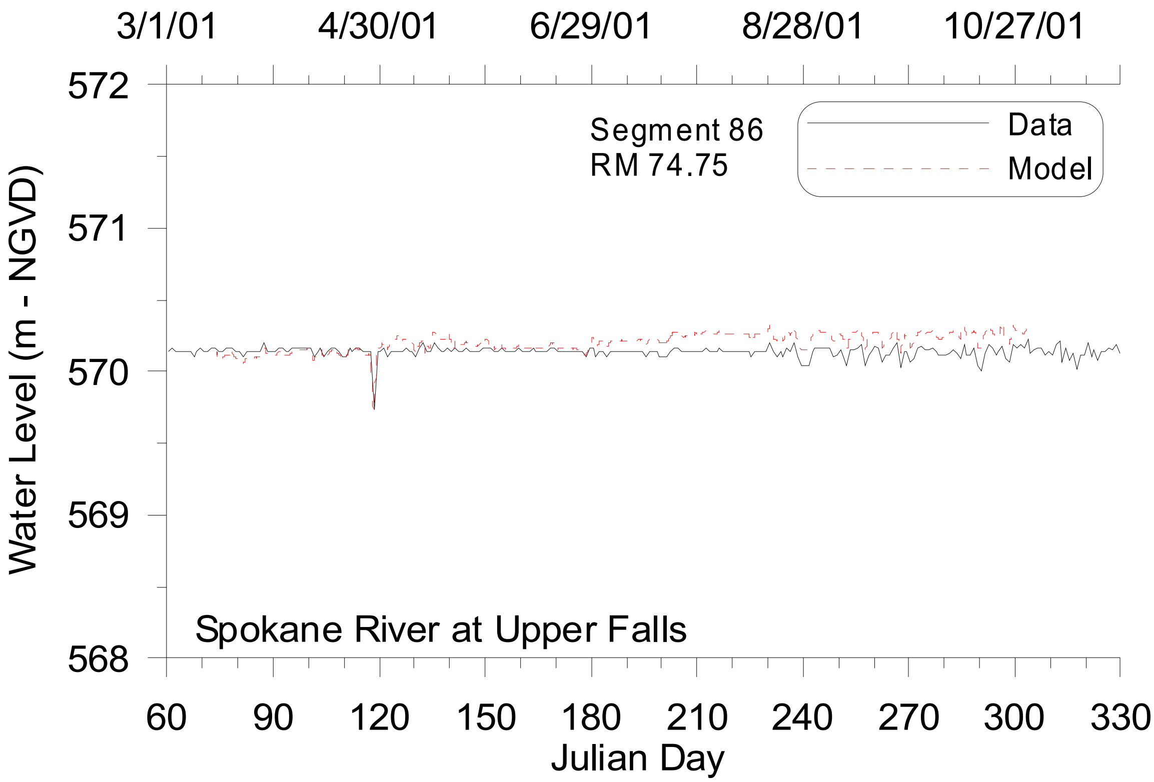

Figure 10. Water level prediction compared with data for the Spokane River at Upper Falls Dam.

Spokane River

The water level was monitored at 3 sites in 2001 as shown in Table 6. Table 7 shows water level error statistics for the three sites. Water level predictions and data were compared for these sites in Figure 11, Figure 12, and Figure 13. The figures show there is less model-data agreement than in previous years and this can be attributed to the influence of the channel geometry at extremely low flow conditions in 2001. The model water level predictions could have been calibrated for this extreme low flow event but it would not have gained much in model flexibility as the flow simulated in the river and its travel time were correct based on the model-data flow comparisons in Figure 14, Figure 15, and Figure 16 for the same three sites. In addition, the water level predictions have negligible influence on the river water quality characteristics. Table 8 shows flow error statistics for the three sites. Flow predictions and data were compared for the three sites in Figure 14, Figure 15, and Figure 16.

Table 6. Spokane River water level data sites

Site	River Mile	Segment
Spokane River at Spokane (USGS: 12422500)	72.9	97
Spokane River at Harvard Rd (USGS: 12419500)	93.8	13
Spokane River at Barker Rd (USGS: 12420500)	90.3	24

Table 7. Water level error statistics for the Spokane River, 2001.

Year:	2001		
Location	N, # of data	AME,	RMS,

	comparisons	m	m
Segment 13, RM 93.8	22074	0.409	0.477
Segment 24, RM 90.3	22074	0.402	0.446
Segment 97, RM 72.9	22074	0.112	0.129

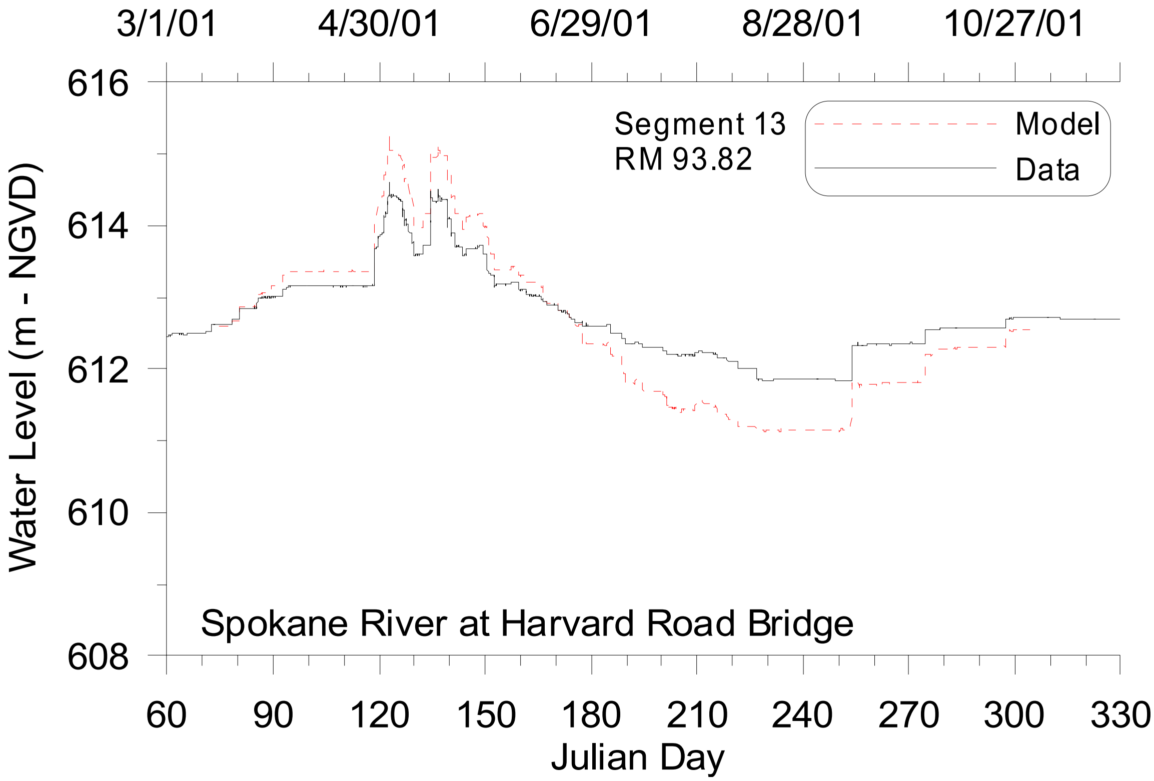

Figure 11. Water level prediction compared with data for the Spokane River at Harvard Road Bridge.

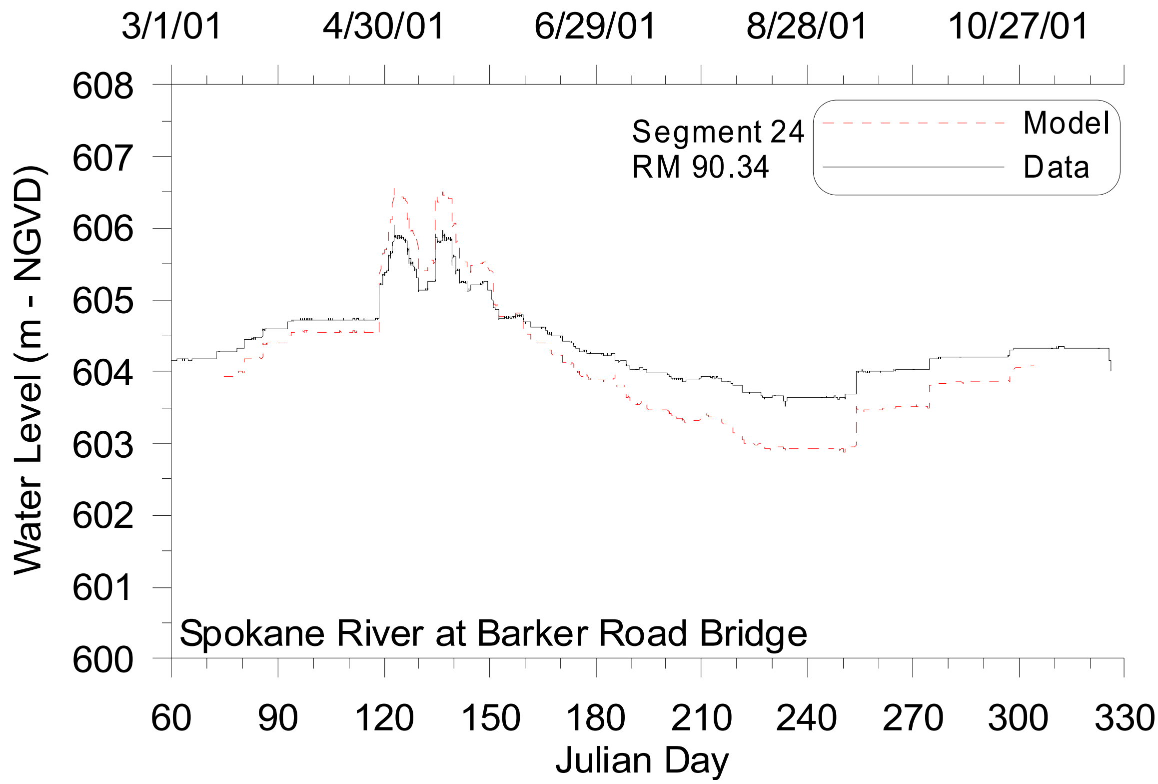

Figure 12. Water level prediction compared with data for the Spokane River at Barker Road Bridge.

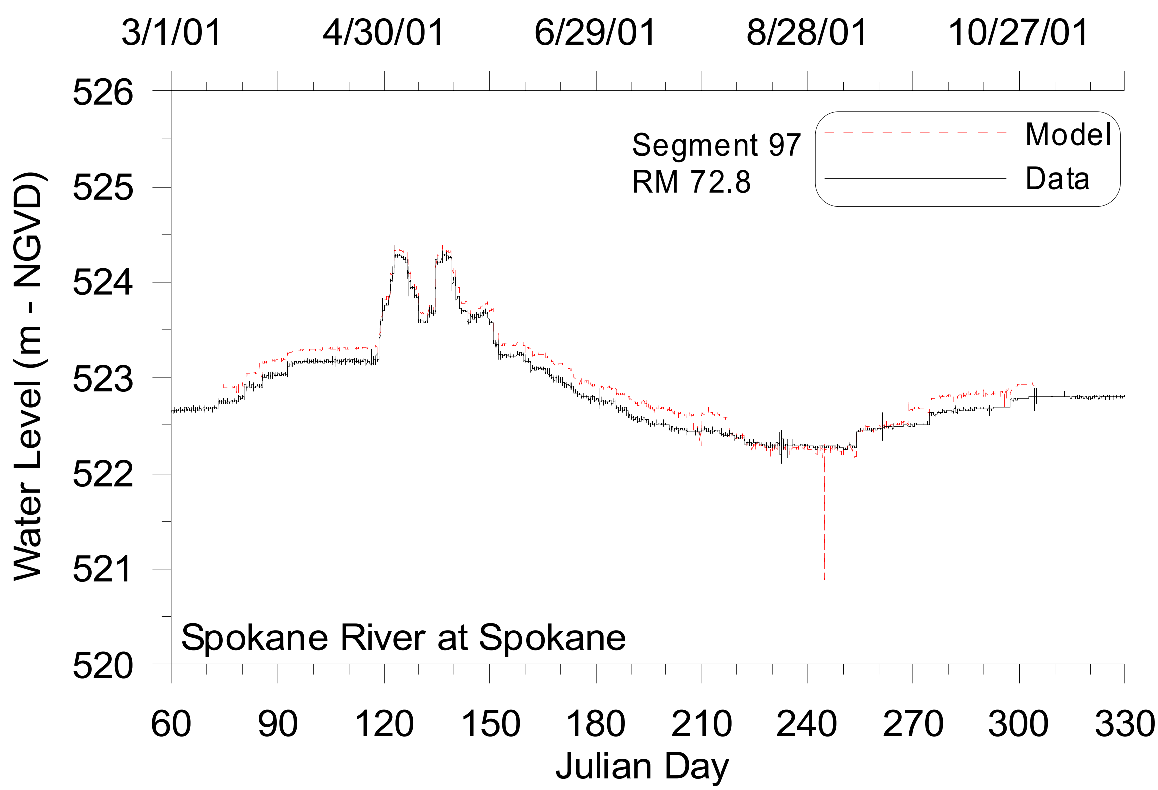

Figure 13. Water level prediction compared with 2001 data for the Spokane River at Spokane.

Table 8. Flow error statistics for the Spokane River, 2001

Year:	2001		
Location	N, # of data comparisons	AME, m^3/s	RMS, m^3/s
Segment 13, RM 93.8	22074	0.79	2.25
Segment 24, RM 90.3	22074	1.16	3.90
Segment 97, RM 72.9	22074	2.75	6.06

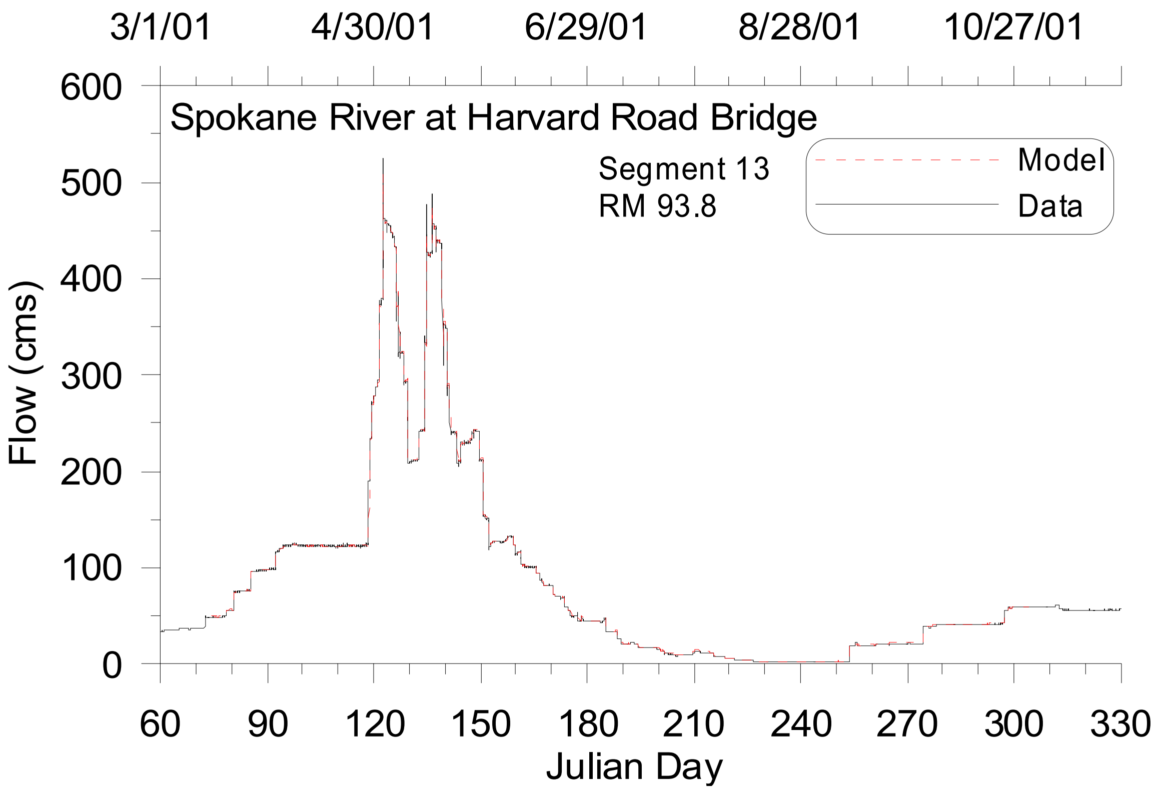

Figure 14. Flow prediction compared with data for the Spokane River at Harvard Road Bridge.

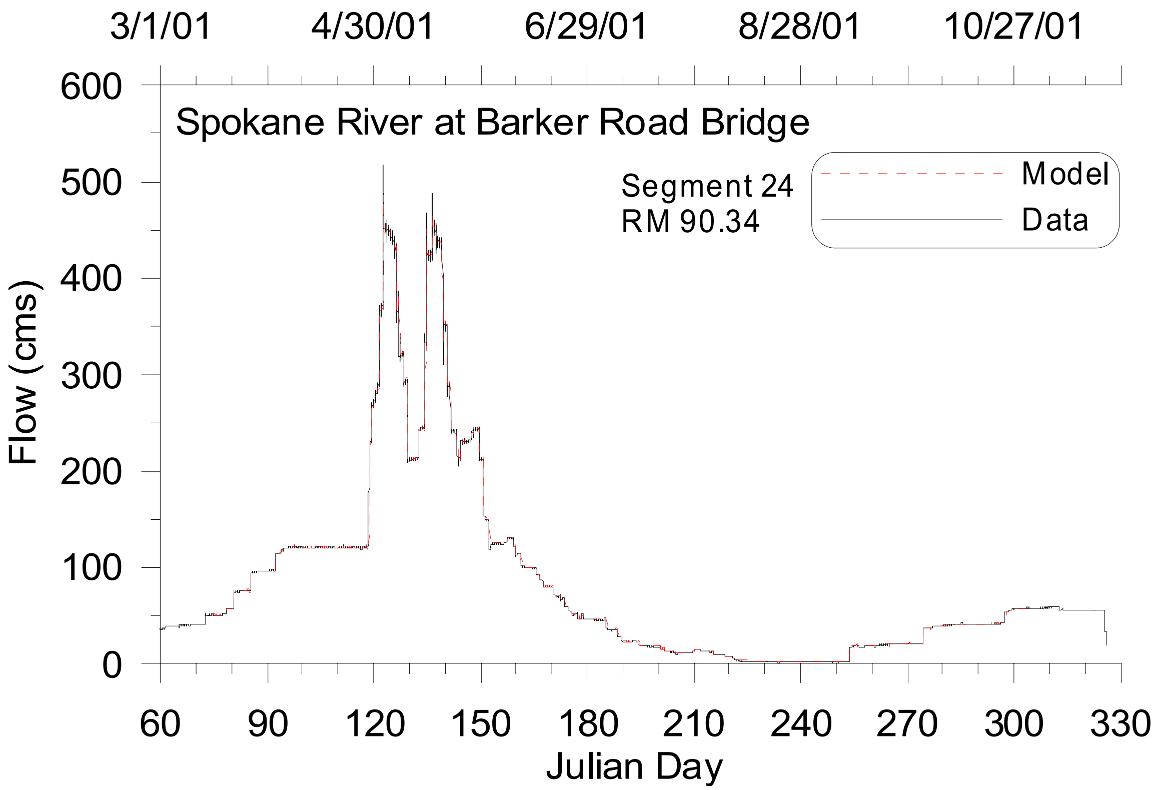

Figure 15. Flow prediction compared with data for the Spokane River at Barker Road Bridge.

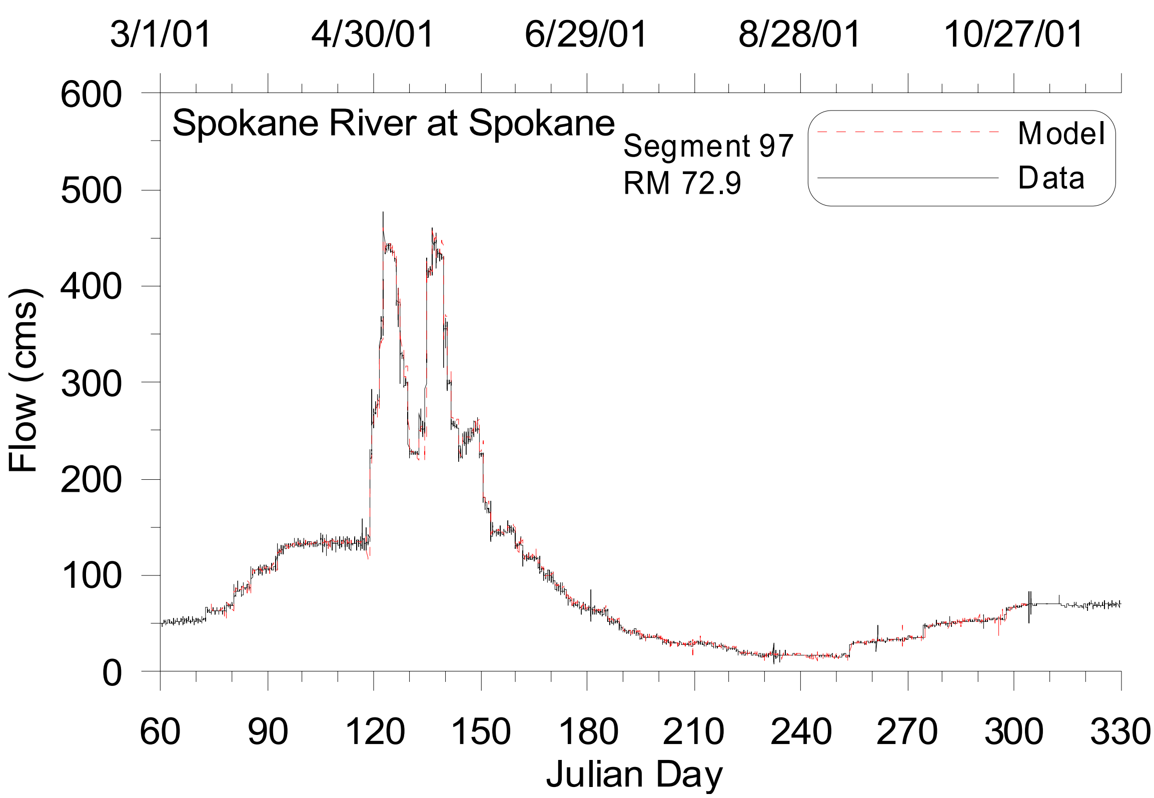

Figure 16. Flow prediction compared with data for the Spokane River at Spokane.

Nine Mile Reservoir

Nine Mile Reservoir Dam is located at approximately RM 58 and the pool extends upstream for 4 miles. The dam and reservoir are operated as a "run-of-the-river" facility. Figure 17 compares the water level data and model results for 2001. Table 9 shows water level statistics for Nine Mile Reservoir.

Table 9. Water level error statistics for Nine Mile Reservoir, 2001.

Year	N, # of data comparisons	Water level model –data error statistics	
		AME, m	RMS error, m
2001	230	0.034	0.044

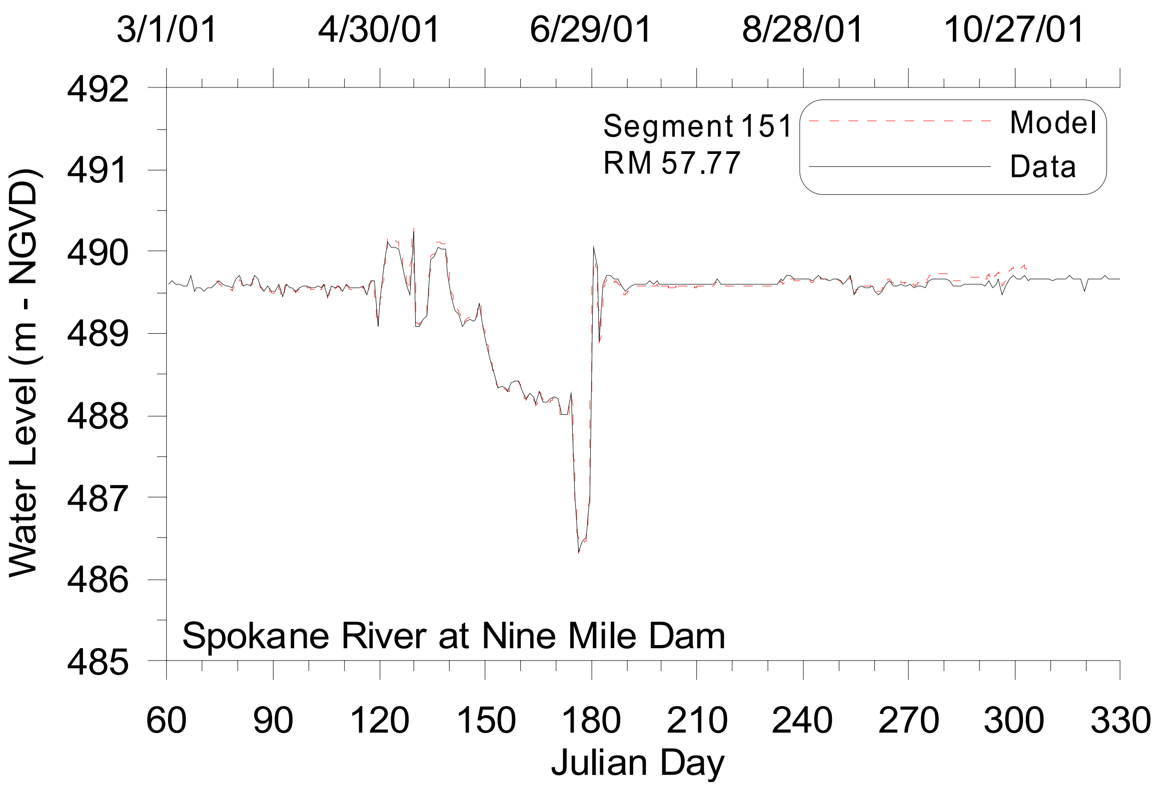

Figure 17. Water level prediction compared with data for the Spokane River at Nine Mile Dam.

Long Lake

Long Lake Dam is located at RM 32.5 and the lake backs up to one mile below Nine Mile Dam at RM 57.8. The lake is operated to store as much water as possible for irrigation with water passing downstream predominantly through turbines. Figure 18 compares the water level data and model results for 2001. Table 10 shows water level statistics for Nine Mile Reservoir in 2001.

Table 10. Water level error statistics for Long Lake, 2001.

Year	N, # of data comparisons	Water level model –data error statistics

		AME, m	RMS error, m
2001	230	0.058	0.065

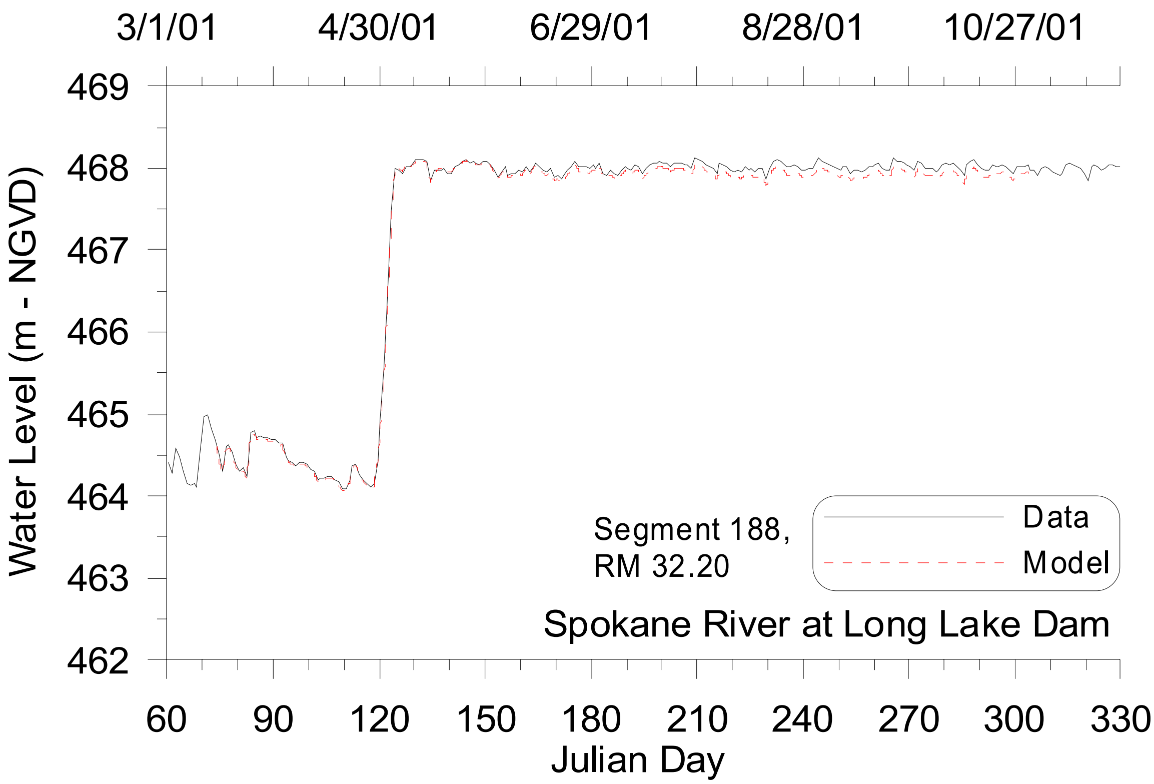

Figure 18. Water level prediction compared with data for the Spokane River at Long Lake Dam.

Temperature Calibration

Model parameters affecting temperature calibration included wind sheltering coefficients, groundwater inflow temperature, and the accurate representation of reservoir outflows. Temperature predictions in Long Lake and Nine Mile Reservoir were particularly sensitive to the wind-sheltering coefficient. In these reservoirs, wind sheltering was increased during the summer in order to simulate the reservoir's vertical temperature profile. The wind-sheltering coefficient was reduced from 0.85 to 0.2 after Julian Day 180. For other sections of the river, wind-sheltering coefficients between 0.5 and 1.00 were applied for the entire year. Groundwater temperatures were estimated from well data.

Vertical Profiles

During 2001 temperature profiles were only collected in Long Lake Reservoir. Model output profiles from each sampling site were compared with 2 data profiles. Table 11 lists the sites in Long Lake where temperature profiles were collected. Figure 19 through Figure 24 show temperature profiles for 2001 in the lake from Station 5 (RM 54.2) downstream to Station 0 (RM 32.7). Table 12 shows overall error statistics for all sites.

Table 11. Long Lake temperature profiles sites for 2001

Site ID	Description	Segment	River

		Number	Mile
LL0	Long Lake at Station 0 (near dam)	187	32.66
LL1	Long Lake at Station 1	180	37.62
LL2	Long Lake at Station 2	174	42.06
LL3	Long Lake at Station 3	168	46.42
LL4	Long Lake at Station 4	161	51.47
LL5	Long Lake at Station 5	157	54.20

Table 12. Temperature profile error statistics, 2001

Site	N, # of data profile comparisons	Temperature model –data error statistics	
		AME, °C	RMS error, °C
LL0	2	1.01	1.20
LL1	2	0.70	0.86
LL2	2	0.73	0.91
LL3	2	0.70	0.97
LL4	2	0.90	1.25
LL5	2	0.72	0.89

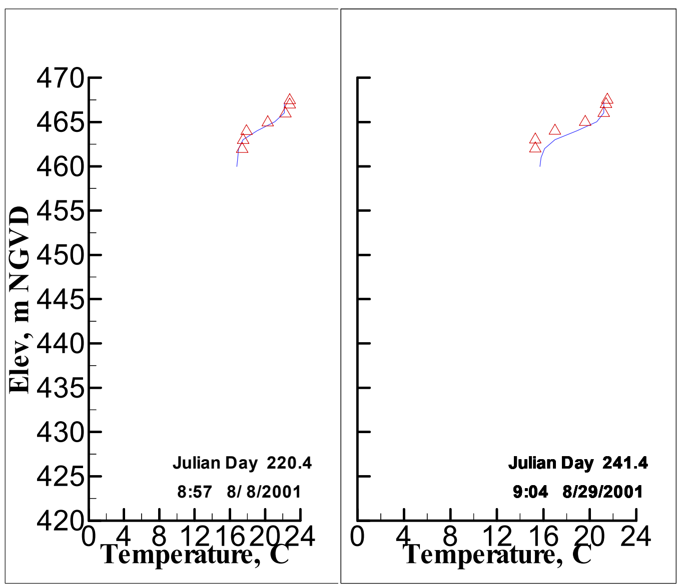

Figure 19. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 5 (Segment 157).

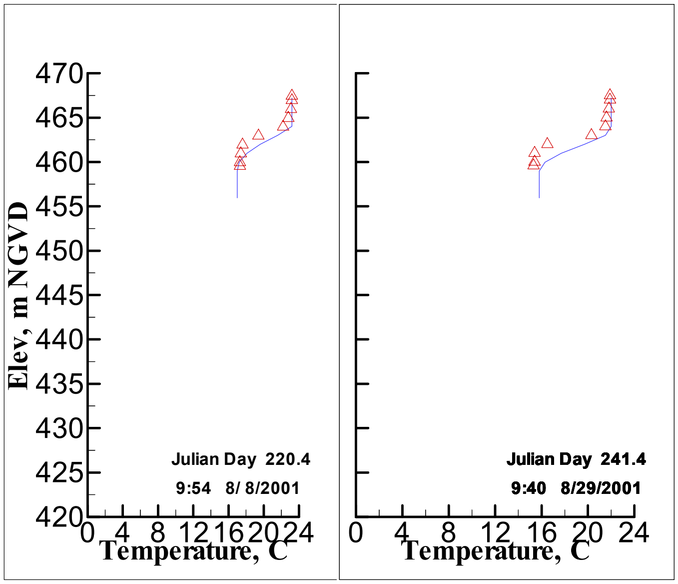

Figure 20. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 4 (Segment 161).

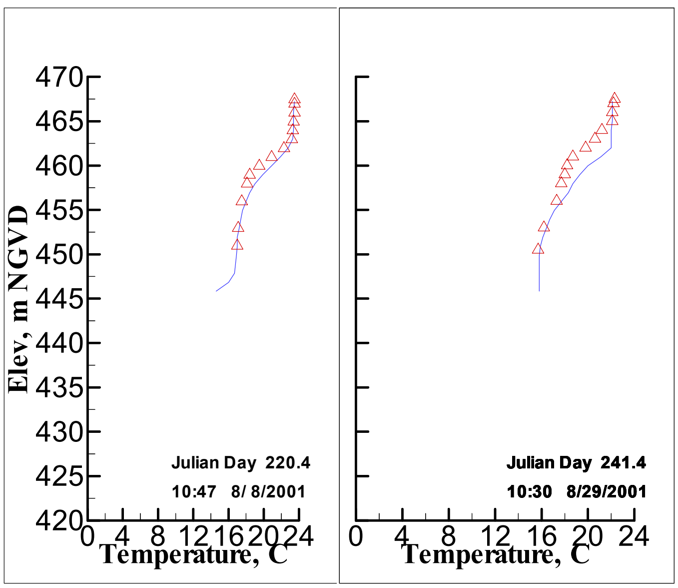

Figure 21. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 3 (Segment 168).

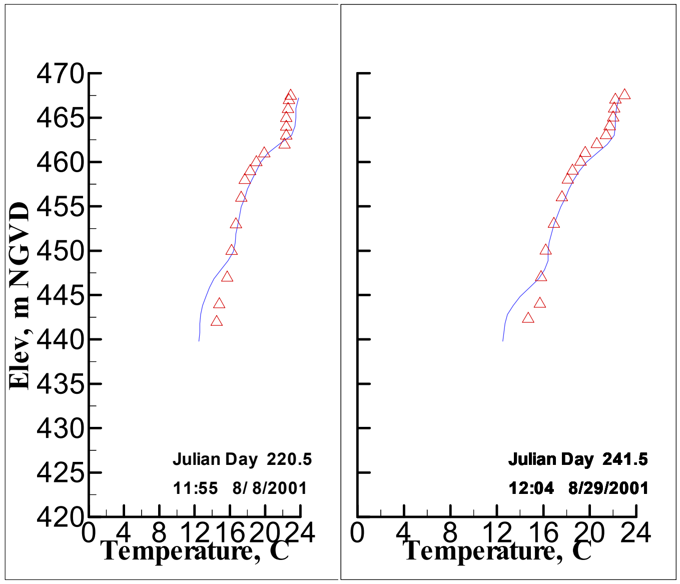

Figure 22. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 2 (Segment 174).

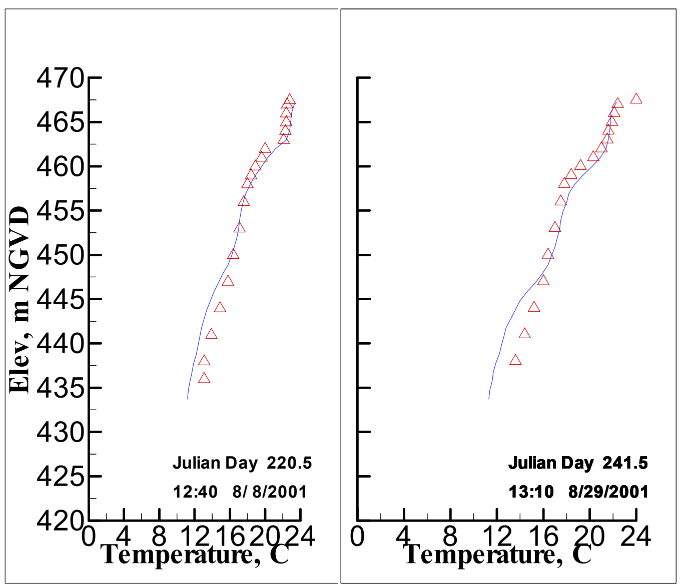

Figure 23. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 1 (Segment 180).

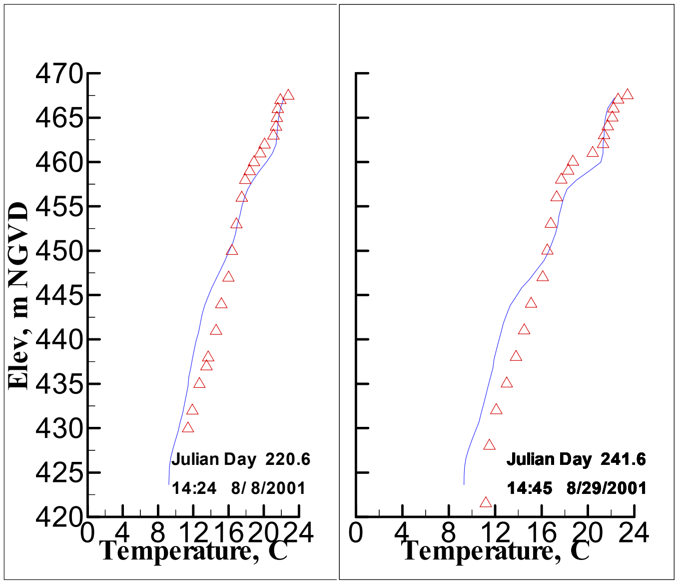

Figure 24. Comparison of model predicted vertical temperature profiles and data for Long Lake at Station 0 (Segment 187).

Time Series

Time series temperature data were collected at several locations along the Spokane River during 2001 as listed in Table 13. The model results represent water temperatures at the surface layer. Figure 25 through Figure 32 plot model prediction vs. data time series graphs for the sites in Table 13. Table 14 shows the model-error statistics for the sites monitored in 2001.

Table 13. Temperature time series sites, 2001

Site ID	Description	Segment Number	River Mile
SPK60.9	Spokane R @ Seven Mile Br	141	60.9
SPK66.0	Spokane R @ Riverside State Park	119	66.0
SPK74.8	Spokane River at Division St Bridge	86	74.8
SPK76.5	Spokane River at Mission Street Bridge	81	76.5
SPK78.0	Spokane R @ Green St. Bridge	73	78.0
SPK79.7	Spokane River at Upriver Dam, downstream	67	79.7
SPK79.8	Spokane R Upstream Upriver Dam Powerhouse	64	79.8
SPK84.7	Spokane R Foot Bridge @ Plante Ferry Park	48	84.7

Table 14. Temperature time series error statistics, 2001

Site	n, # of data comparisons	Temperature, ^{o}C model – data error statistics	
		AME, mhos/cm	RMS error, mhos/cm
SPK60.9	576	0.66	0.79
SPK66.0	12	0.80	0.99
SPK74.8	580	1.90	1.98

SPK76.5	11	1.87	2.41
SPK78.0	8	1.53	2.29
SPK79.7	11	1.00	1.20
SPK79.8	16	2.18	2.39
SPK84.7	2	1.52	1.77

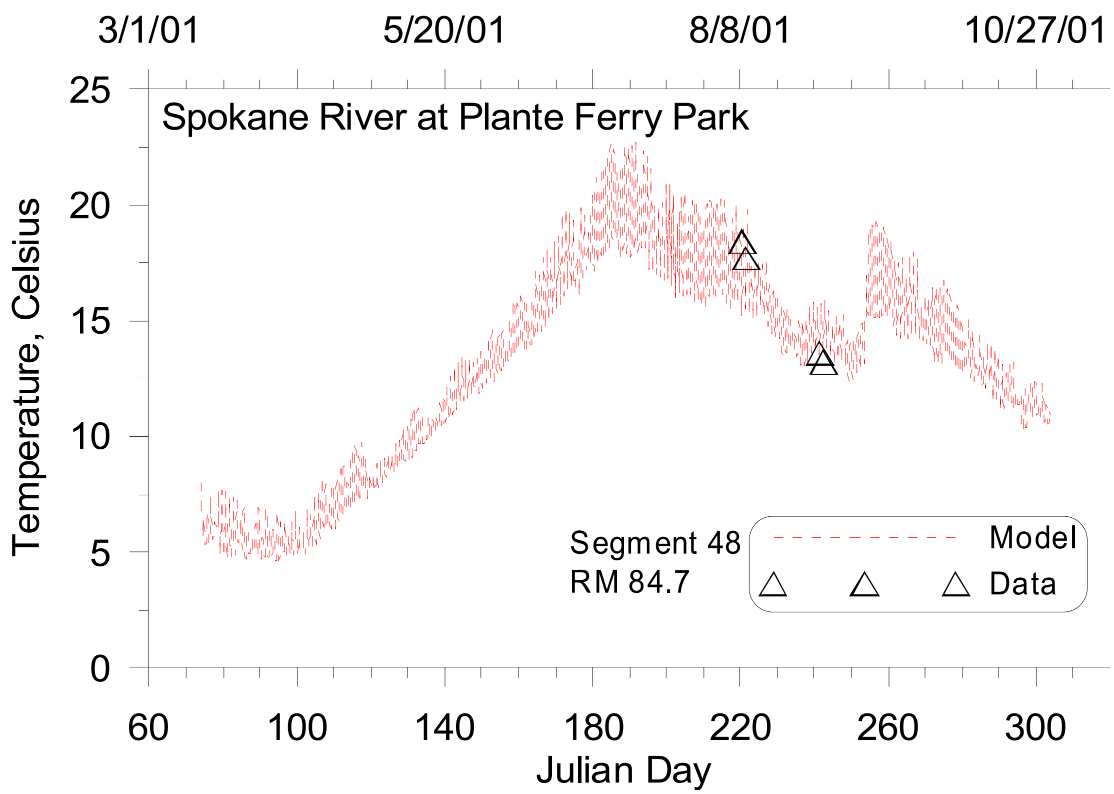

Figure 25. Model temperature predictions compared with data collected at Plante Ferry Park

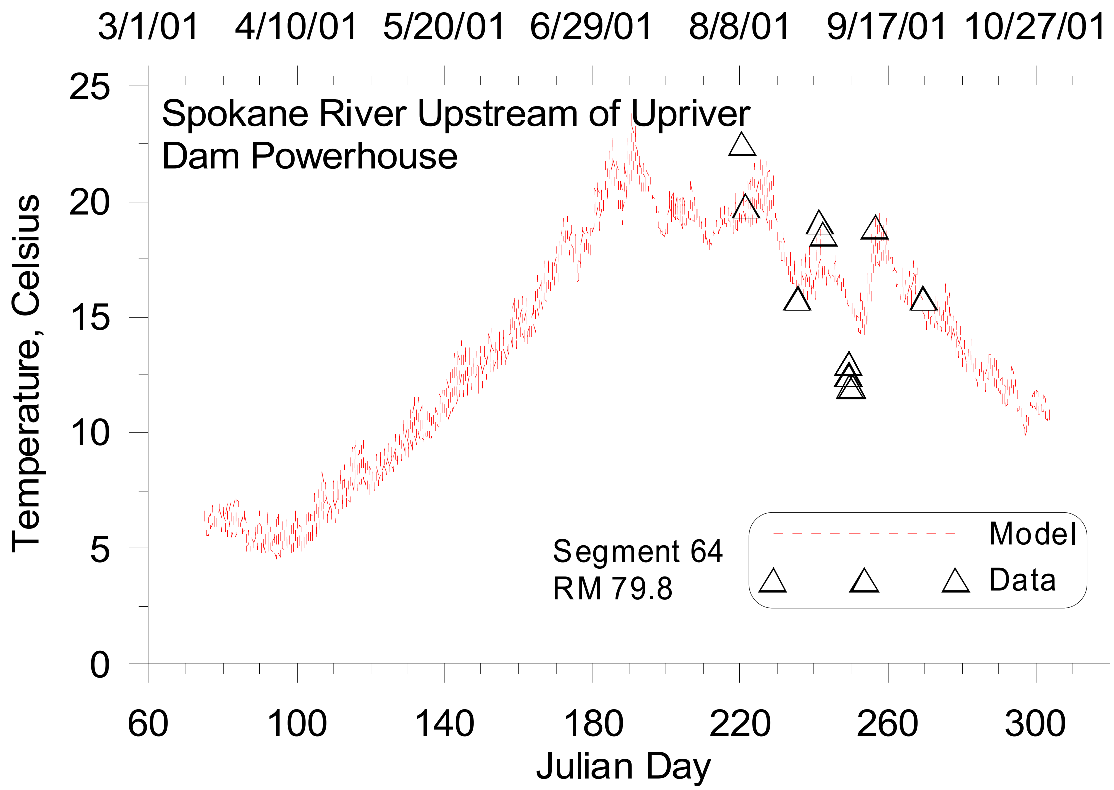

Figure 26. Model temperature predictions compared with data collected upstream of Upriver Dam

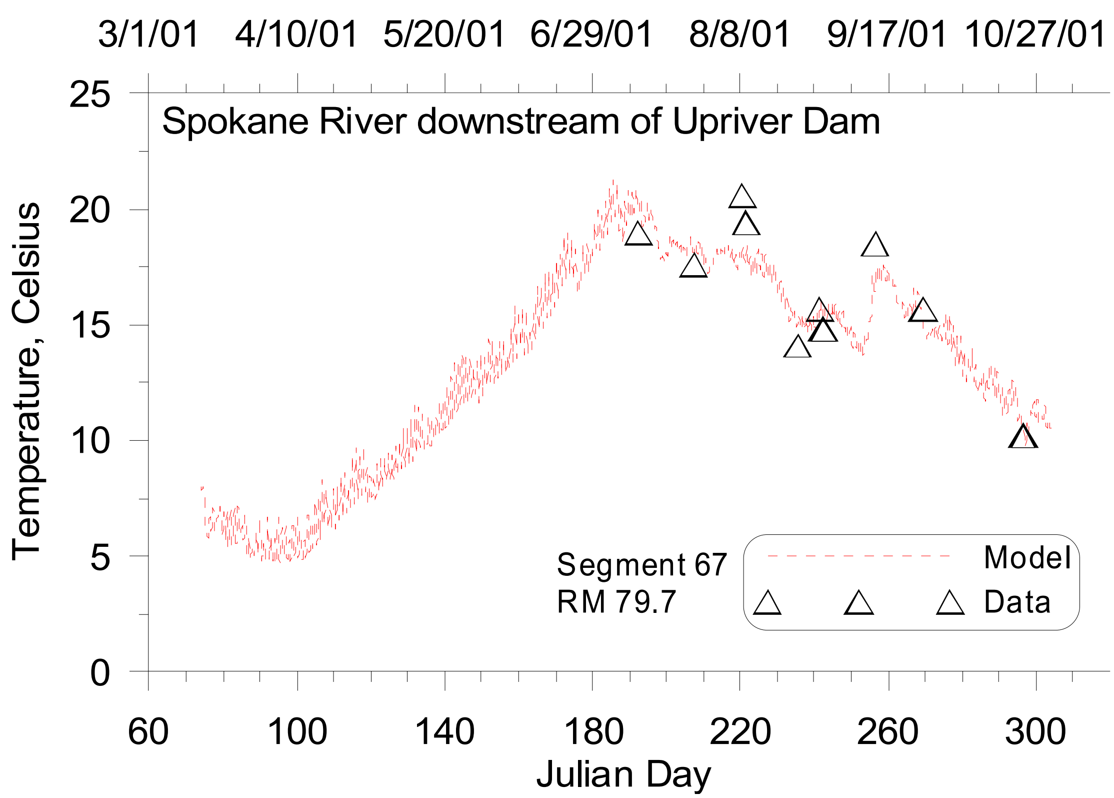

Figure 27. Model temperature predictions compared with data collected downstream of Upriver Dam

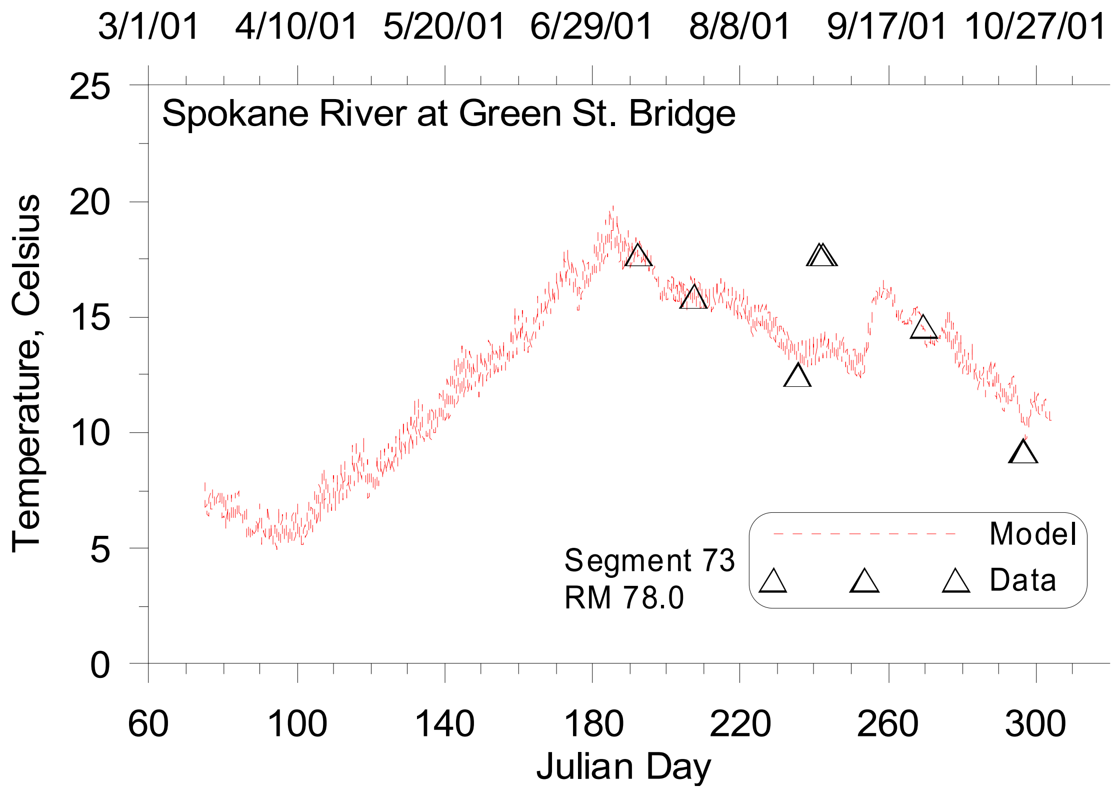

Figure 28. Model temperature predictions compared with data collected at Green St. Bridge

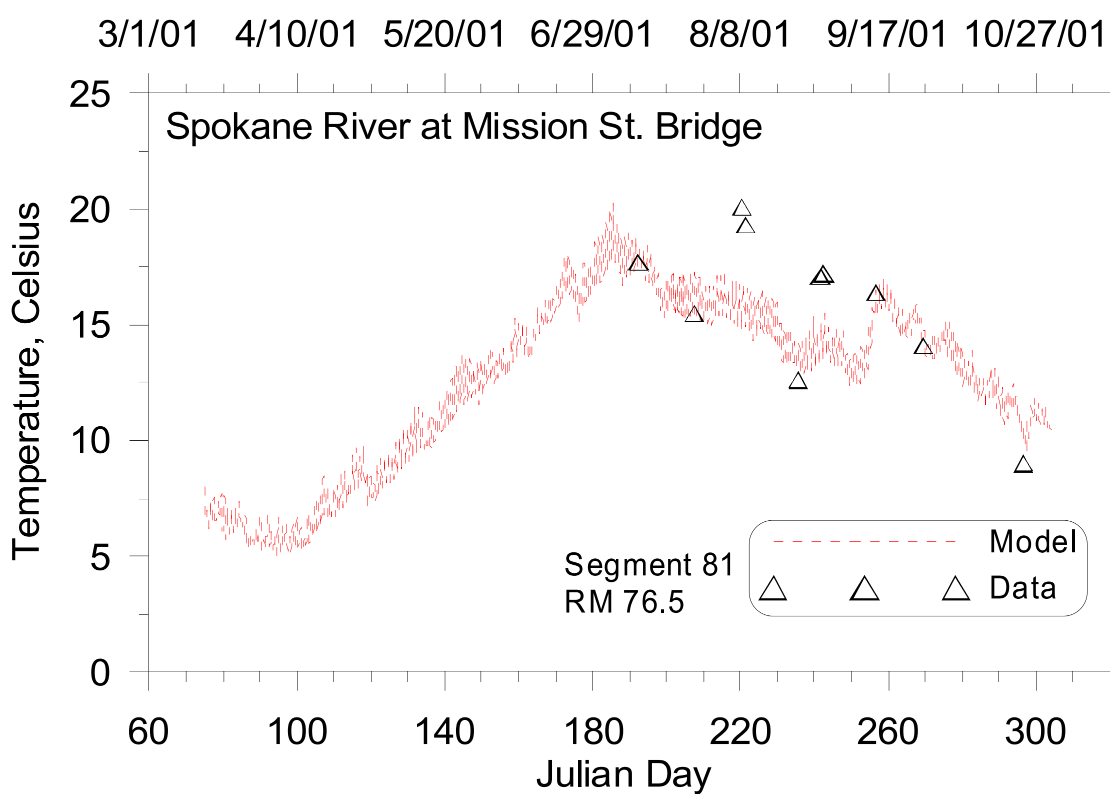

Figure 29. Model temperature predictions compared with data collected at Mission St. Bridge

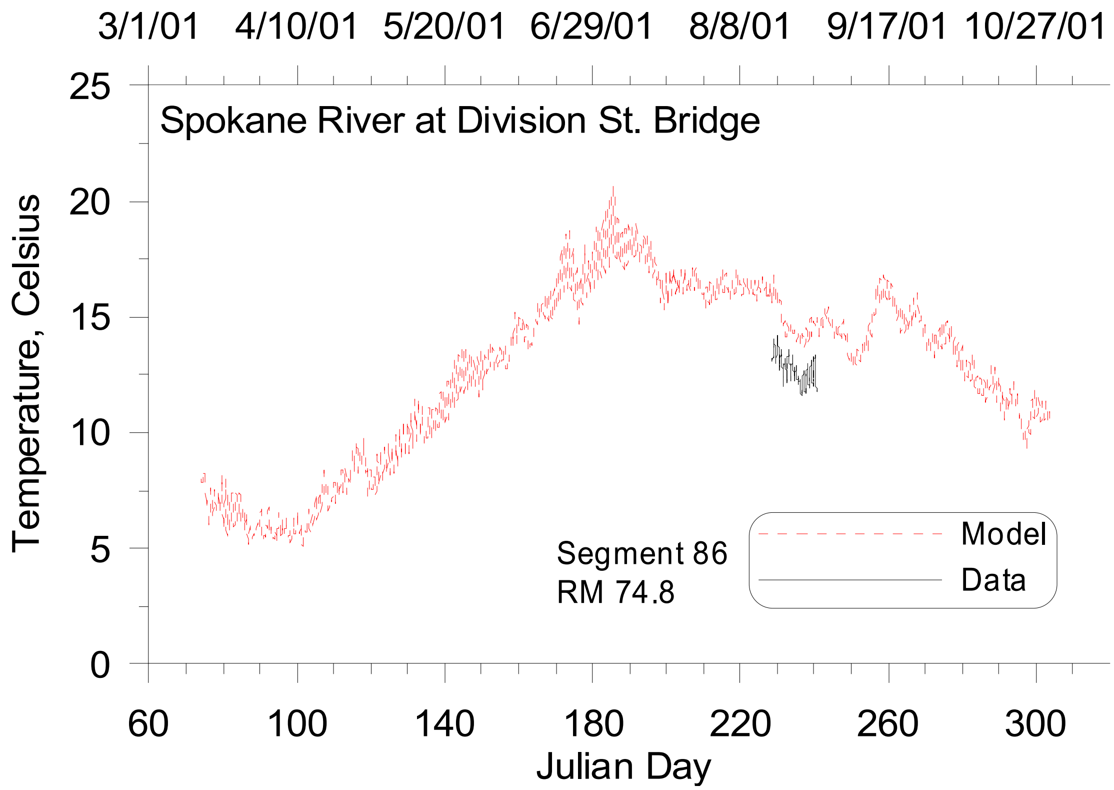

Figure 30. Model temperature predictions compared with data collected at Division St. Bridge

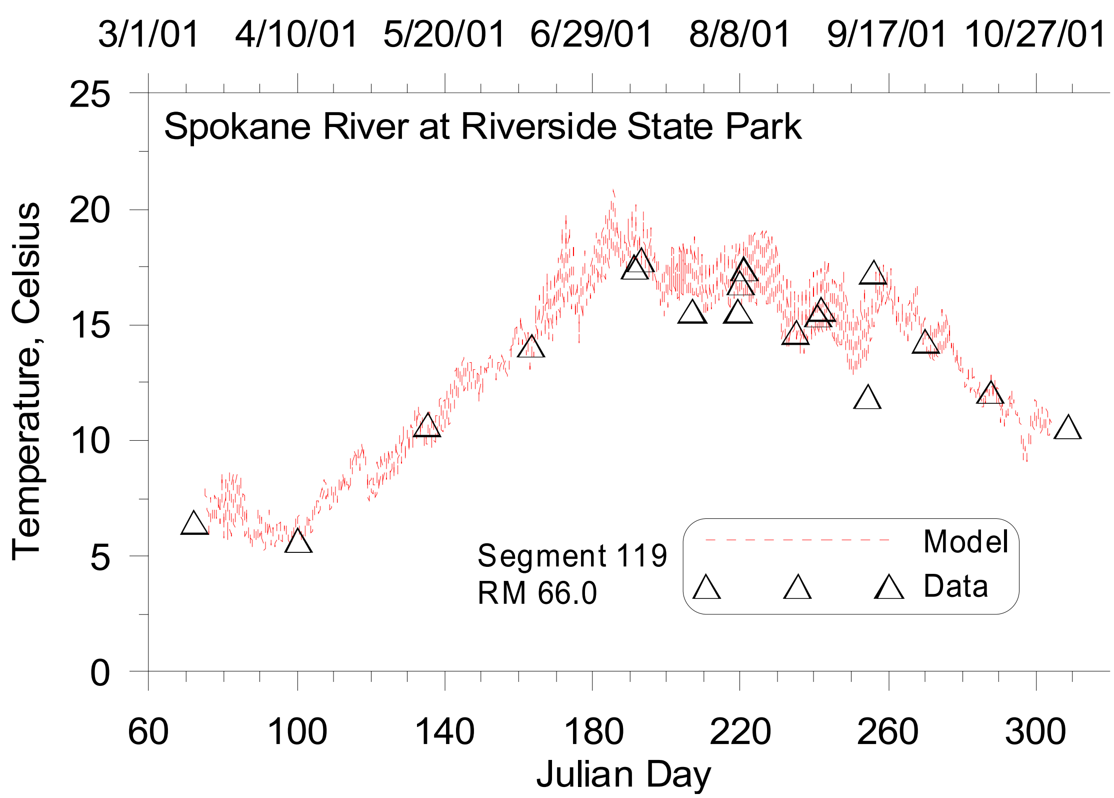

Figure 31. Model temperature predictions compared with data collected at Riverside State Park

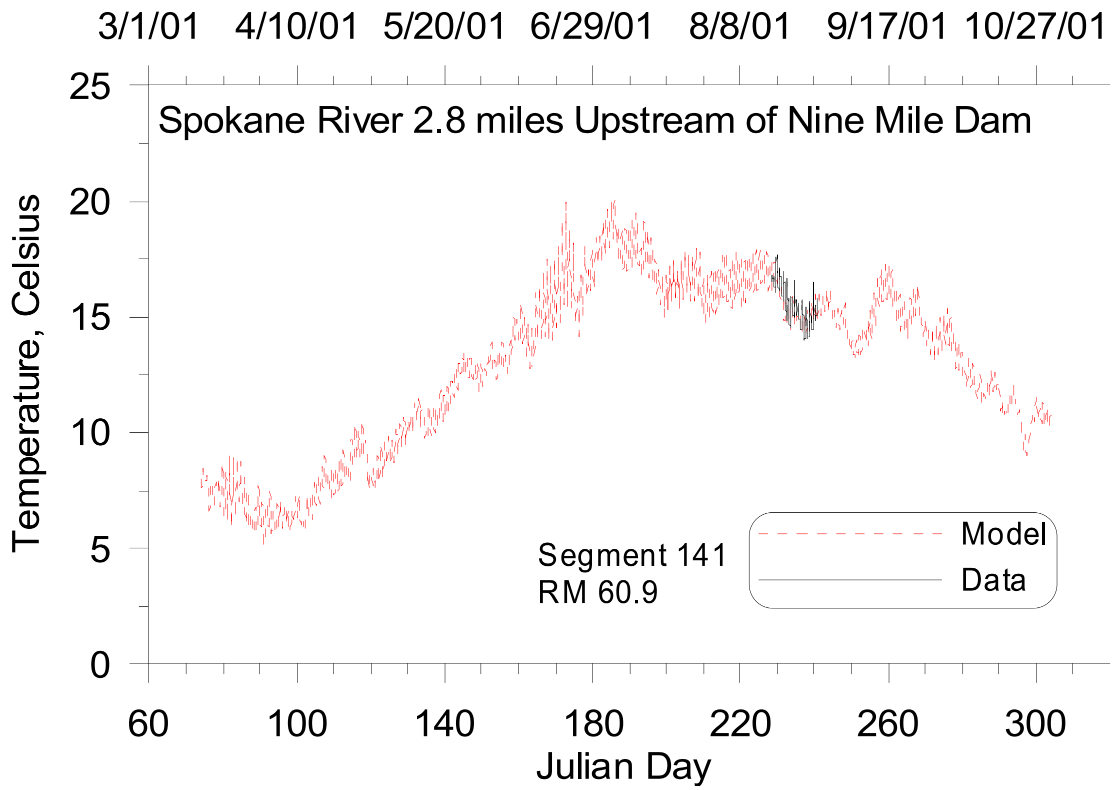

Figure 32. Model temperature predictions compared with data collected at below Nine Mile Dam

Water Quality

The general approach toward water quality calibration was to keep coefficient values close to commonly accepted literature values. Vertical profile and time series water quality data were collected at several sites throughout the Upper Spokane basin. Some sites have limited time periods or number of constituents monitored. Table 15 shows a general list of the sites with columns indicating which sites have vertical profiles and time series comparisons. Water quality model parameters used during the calibration are shown in Table 16.

Table 15. Water quality sites monitored in 2001

SiteID	Description	Seg	RM	2001 Vert. profile	2001 Time Series
LL0	Long Lake @ Station 0 (near dam)	187	32.7	YES	
LL1	Long Lake @ Station 1	180	37.6	YES	
LL2	Long Lake @ Station 2	174	42.1	YES	
LL3	Long Lake @ Station 3	168	46.4	YES	
LL4	Long Lake @ Station 4	161	51.5	YES	
LL5	Long Lake @ Station 5	157	54.2	YES	
SPK57.7	Spokane River directly below 9 Mile Dam	151	57.7		YES
SPK60.9	Spokane River 2.8 miles above Nine mile Dam	141	60.9		YES
SPK62.0	Spokane R @ Seven Mile Br	135	62.0		YES
SPK66.0	Spokane R @ Riverside State Park	119	66.0		YES
SPK67.6	Spokane R Upstream Spokane WTP	114	67.6		YES

Table 15. Water quality sites monitored in 2001					
SiteID	Description	Seg	RM	2001 Vert. profile	2001 Time Series
SPK69.8	Spokane R near Fort Wright Bridge	106	69.8		YES
SPK74.8	Spokane River at Division St Bridge	86	74.8		YES
SPK76.5	Spokane River at Mission Street Bridge	80	76.5		YES
SPK78.0	Spokane R @ Green St. Bridge	73	78.0		YES
SPK79.7	Spokane River at Upriver Dam, downstream	67	79.7		YES
SPK79.8	Spokane R Upstream Upriver Dam Powerhouse	64	79.8		YES
SPK84.7	Spokane R Foot Bridge @ Plante Ferry Park	48	84.7		YES
SPK87.8	Spokane R @ Sullivan Rd. Bridge	36	87.8		YES
SPK90.4	Spokane R @ Barker Rd. Bridge	24	90.4		YES
SPK93.0	Spokane R @ Harvard Rd. Bridge	17	93.0		YES

Table 16. W2 Model Water Quality Parameters				
Variable	**Description**	**Units**	**Typical values***	**Calibration Values**
Hydrodynamics and Longitudinal Transport				
AX	Longitudinal eddy viscosity (for momentum dispersion)	m^2/sec	1	1
DX	Longitudinal eddy diffusivity (for dispersion of heat and constituents)	m^2/sec	1	1
Temperature				
CBHE	Coefficient of bottom heat exchange	Wm^2/sec	7.0 x 10-8	7.0 x 10-8
TSED	Sediment (ground) temperature	^oC	12.8	11.5
WSC	Wind sheltering coefficient		0.85	0.2-1.4
BETA	Fraction of incident solar radiation absorbed at the water surface		0.45	0.45
Water Quality				
EXH20	Extinction for water	/m	0.25	0.25
EXSS	Extinction due to inorganic suspended solids	m^3/m/g	0.01	0.01
EXOM	Extinction due to organic suspended solids	m^3/m/g	0.17	0.10
EXA	Extinction due to organic algal type 1	m^3/m/g	0.10	0.10
SSS	Suspended solids settling rate	m/day	2	1.5
AG1	Algal growth rate for algal type 1	/day	1.1	1.5
AM1	Algal mortality rate for algal type 1	/day	0.01	0.1
AE1	Algal excretion rate for algal type 1	/day	0.01	0.04
AR1	Algal dark respiration rate for algal type 1	/day	0.02	0.04
AS1	Algal settling rate for algal type 1	/day	0.14	0.2
ASAT1	Saturation intensity at maximum photosynthetic rate for algal type 1	W/m^2	150	40
APOM1	Fraction of algal biomass lost by mortality to detritus for algal type 1		0.8	0.8
AT11	Lower temperature for algal growth for algal type 1	^oC	10	8
AT21	Lower temperature for maximum algal growth for algal type 1	^oC	30	10

Table 16. W2 Model Water Quality Parameters				
Variable	Description	Units	Typical values*	Calibration Values
AT31	Upper temperature for maximum algal growth for algal type 1	^oC	35	20
AT41	Upper temperature for algal growth for algal type 1	^oC	40	30
AK11	Fraction of algal growth rate at ALGT1 for algal type 1		0.1	0.1
AK21	Fraction of maximum algal growth rate at ALGT2 for algal type 1		0.99	0.99
AK31	Fraction of maximum algal growth rate at ALGT3 for algal type 1		0.99	0.99
AK41	Fraction of algal growth rate at ALGT4 for algal type 1		0.1	0.1
ALGP-A1	Stoichiometric equivalent between organic matter and phosphorus for algal type 1		0.011	0.005
ALGN-A1	Stoichiometric equivalent between organic matter and nitrogen for algal type 1		0.08	0.08
ALGC-A1	Stoichiometric equivalent between organic matter and carbon for algal type 1		0.45	0.45
EG1	Periphyton growth rate for Periphyton type 1	/day	1.1	1.5
EM1	Periphyton mortality rate for Periphyton type 1	/day	0.01	0.10
EE1	Periphyton excretion rate for Periphyton type 1	/day	0.01	0.04
ER1	Periphyton dark respiration rate for Periphyton type 1	/day	0.02	0.04
EB1	Periphyton burial rate for Periphyton type 1	/day	0.001	0.001
ESAT1	Saturation intensity at maximum photosynthetic rate for Periphyton type 1	W/m^2	150	150
EPOM1	Fraction of Periphyton biomass lost by mortality to detritus for Periphyton type 1		0.8	0.8
ET11	Lower temperature for Periphyton growth for Periphyton type 1	^oC	10	1
ET21	Lower temperature for maximum Periphyton growth for Periphyton type 1	^oC	30	3
ET31	Upper temperature for maximum Periphyton growth for Periphyton type 1	^oC	35	20
ET41	Upper temperature for Periphyton growth for Periphyton type 1	^oC	40	30
EK11	Fraction of Periphyton growth rate at ALGT1 for Periphyton type 1		0.1	0.1
EK21	Fraction of maximum Periphyton growth rate at ALGT2 for Periphyton type 1		0.99	0.99
EK31	Fraction of maximum Periphyton growth rate at ALGT3 for Periphyton type 1		0.99	0.99
EK41	Fraction of Periphyton growth rate at ALGT4 for Periphyton type 1		0.1	0.1
EP-E1	Stoichiometric equivalent between organic matter and phosphorus for Periphyton type 1		0.011	0.005
EN-E1	Stoichiometric equivalent between organic matter and nitrogen for Periphyton type 1		0.08	0.08
EC-E1	Stoichiometric equivalent between organic matter and carbon for Periphyton type 1		0.45	0.45
LDOMDK	Labile DOM decay rate	/day	0.12	0.08
LRDDK	Labile to refractory decay rate	/day	0.001	0.001

Table 16. W2 Model Water Quality Parameters				
Variable	**Description**	**Units**	**Typical values***	**Calibration Values**
RDOMDK	Maximum refractory decay rate	/day	0.001	0.001
LPOMDK	Labile Detritus decay rate	/day	0.06	0.08
POMS	Detritus settling rate	m/day	0.35	0.1
RPOMDK	Refractory Detritus decay rate	/day		0.001
OMT1	Lower temperature for organic matter decay	^{o}C	4	4
OMT2	Lower temperature for maximum organic matter decay	^{o}C	20	30
OMK1	Fraction of organic matter decay rate at OMT1		0.1	0.1
OMK2	Fraction of organic matter decay rate at OMT2		0.99	0.99
SDK	Sediment decay rate	/day	0.06	0.1
PARTP	Phosphorous partitioning coefficient for suspended solids		1.2	0
AHSP	Algal half-saturation constant for phosphorous	g/m	0.009	0.003
NH4DK	Ammonia decay rate (nitrification rate)	/day	0.12	0.40
AHSN	Algal half-saturation constant for ammonia	g/m^3	0.014	0.014
NH4T1	Lower temperature for ammonia decay	^{o}C	5	5
NH4T2	Lower temperature for maximum ammonia decay	^{o}C	20	25
NH4K1	Fraction of nitrification rate at NH4T1		0.1	0.1
NH4K2	Fraction of nitrification rate at NH4T2		0.99	0.99
NO3DK	Nitrate decay rate (denitrification rate)	/day	0.102	0.05
NO3T1	Lower temperature for nitrate decay	^{o}C	5	5
NO3T2	Lower temperature for maximum nitrate decay	^{o}C	20	25
NO3K1	Fraction of denitrification rate at NO3T1		0.1	0.1
NO3K2	Fraction of denitrification rate at NO3T2		0.99	0.99
O2NH4	Oxygen stoichiometric equivalent for ammonia decay		4.57	4.57
O2OM	Oxygen stoichiometric equivalent for organic matter decay		1.4	1.4
O2AR	Oxygen stoichiometric equivalent for dark respiration		1.4	1.1
O2AG	Oxygen stoichiometric equivalent for algal growth		1.4	1.4
BIOP	Stoichiometric equivalent between organic matter and phosphorus		0.011	0.005
BION	Stoichiometric equivalent between organic matter and nitrogen		0.08	0.08
BIOC	Stoichiometric equivalent between organic matter and carbon		0.45	0.45
O2LIM	Dissolved oxygen concentration at which anaerobic processes begin	g/m^3	0.05	0.1
* Cole and Wells (2000)				

Conductivity

Conductivity was modeled as a conservative constituent and provided a check for the model's overall water balance. The groundwater conductivity was generally higher than the conductivity of water at the state line upstream boundary. Vertical profiles of conductivity in Long Lake were also used to determine if the zone of interflow, which was caused by cool Spokane River inflows, was being simulated.

Conductivity profiles were collected in Long Lake in 2001 for 2 days. No profiles were collected upstream of Long Lake in 2001. Figure 33 to Figure 38 show conductivity profile data and model results for six locations in Long Lake from RM 32.7 to 54.2. Table 17 shows AME and RMS error statistics for the conductivity vertical profiles. Figure 39 to Figure 45 show time series plots of conductivity for five locations along the Spokane River system. Table 18 includes model-data error statistics for the time series comparisons.

Conductivity data was collected by Columbia Analytical Services (CAS) in the field and measured in the lab and Spokane County measured conductivity data. Based on an analysis Bob Cusimano, WA DOE, conducted there were a biases between data collected by CAS and county and the data collected by DOE. Based on the analysis the following conductivity relationships were developed:

1. CAS (LAB) vs. CAS field, y = 0.8897x
2. CAS (LAB) vs. Spokane County, y = 0.9176x
3. CAS (LAB) vs. WA DOE, y = 1.0851x

The correlations were then used to "standardize" the conductivity measurements >70 umhos/cm from the CAS and Spokane County data sets to the data collected by DOE. The conductivity data was only adjusted for grab samples collected by CAS and Spokane County and is plotted with data from DOE in the time series graphs. The model-data error statistics in Table 18 reflect the model compared to the standardized conductivity data.

Table 17. Conductivity profile error statistics, 2001

Site	n, # of data profile comparisons	Conductivity model –data error statistics	
		AME, mhos/cm	RMS error, mhos/cm
LL0	2	17.42	21.09
LL1	2	24.21	28.42
LL2	2	24.56	36.89
LL3	2	31.07	33.99
LL4	2	24.41	28.17
LL5	2	22.28	26.26

Table 18. Conductivity time series error statistics, 2001

Site	n, # of data comparisons	Conductivity model –data error statistics	
		AME, mhos/cm	RMS error, mhos/cm
SPK60.9	576	23.0	23.3
SPK66.0	30	13.2	14.8
SPK74.8	580	57.2	57.2
SPK76.5	16	19.4	27.2
SPK78.0	12	18.3	23.5

SPK79.7	19	42.0	44.5
SPK79.8	19	63.3	65.2
SPK84.7	10	68.1	70.2

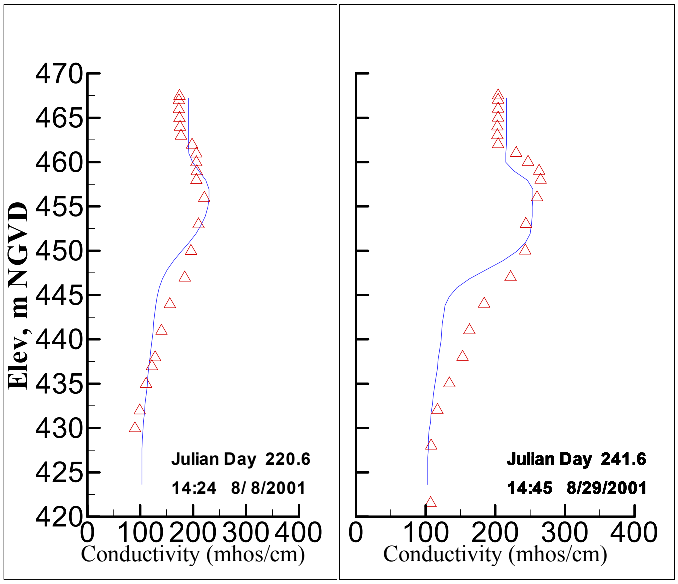

Figure 33. Comparison of model predicted vertical conductivity profiles and data for Long Lake at Station 0 (Segment 187).

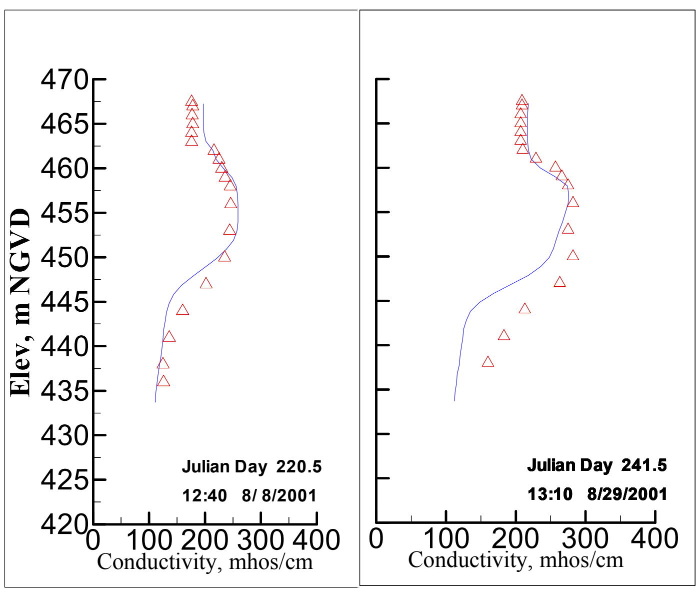

Figure 34. Comparison of model predicted vertical conductivity profiles and data for Long Lake at Station 1 (Segment 180).

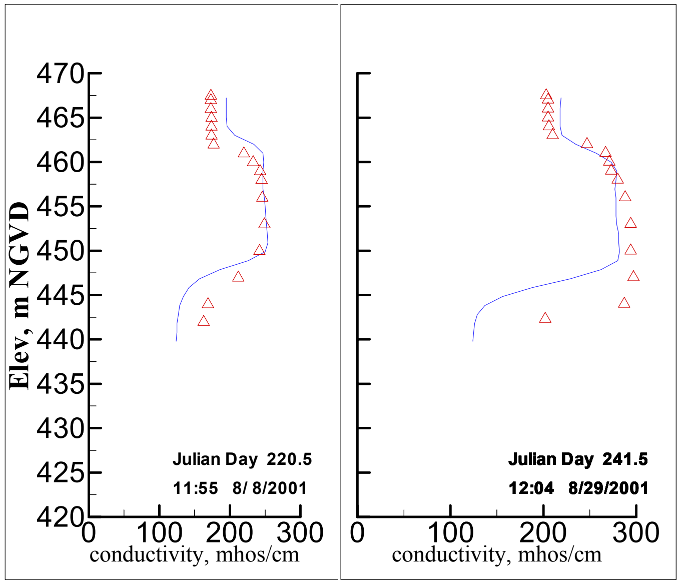

Figure 35. Comparison of model predicted vertical conductivity profiles and data for Long Lake at Station 2 (Segment 174).

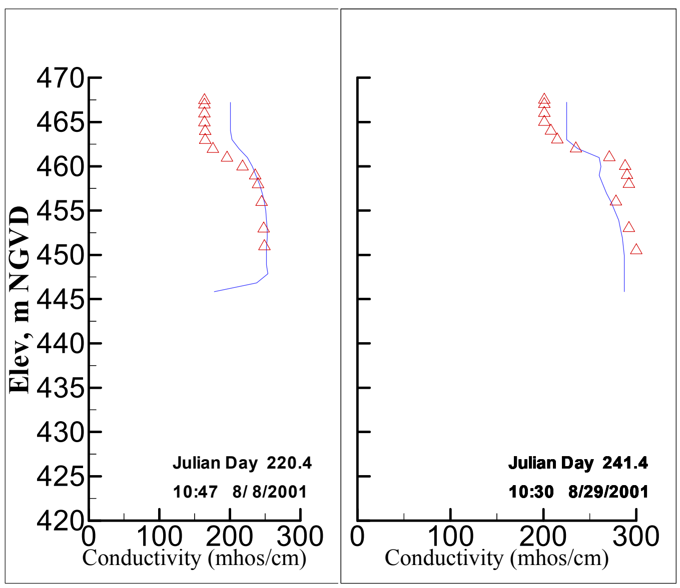

Figure 36. Comparison of model predicted vertical conductivity profiles and data for Long Lake at Station 3 (Segment 168).

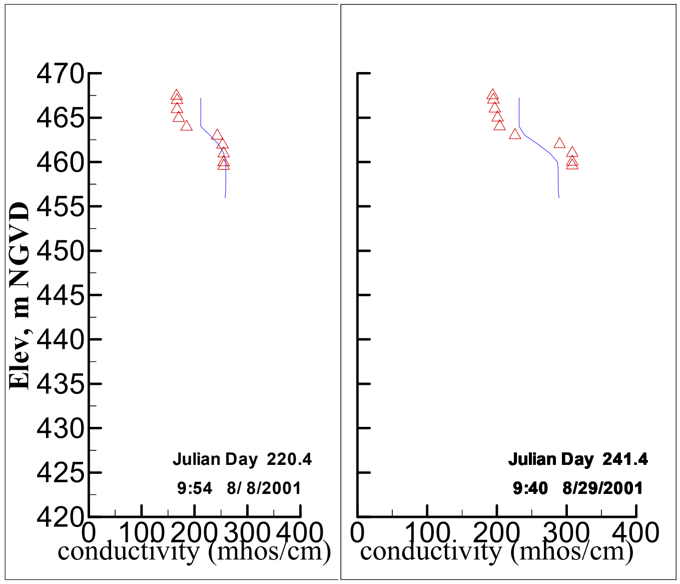

Figure 37. Comparison of model predicted vertical conductivity profiles and 2001 for Long Lake at Station 4 (Segment 161).

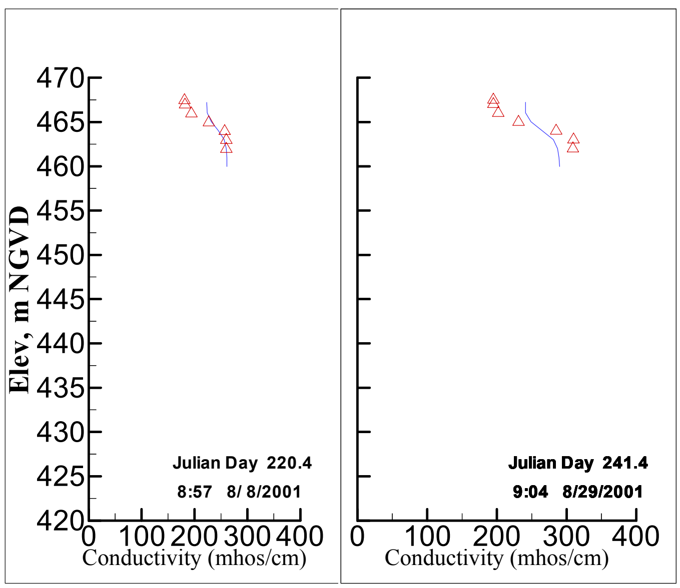

Figure 38. Comparison of model predicted vertical conductivity profiles and data for Long Lake at Station 5 (Segment 157).

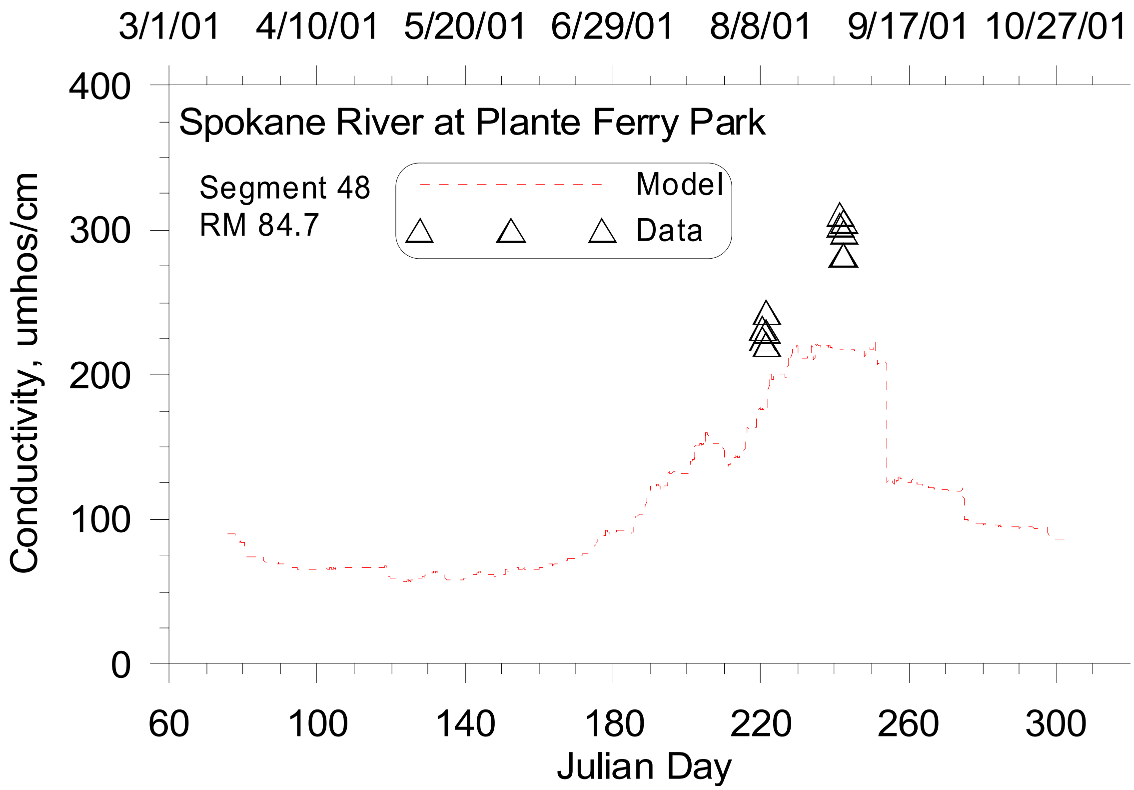

Figure 39. Comparison of model predicted conductivity and data at Plante Ferry Park

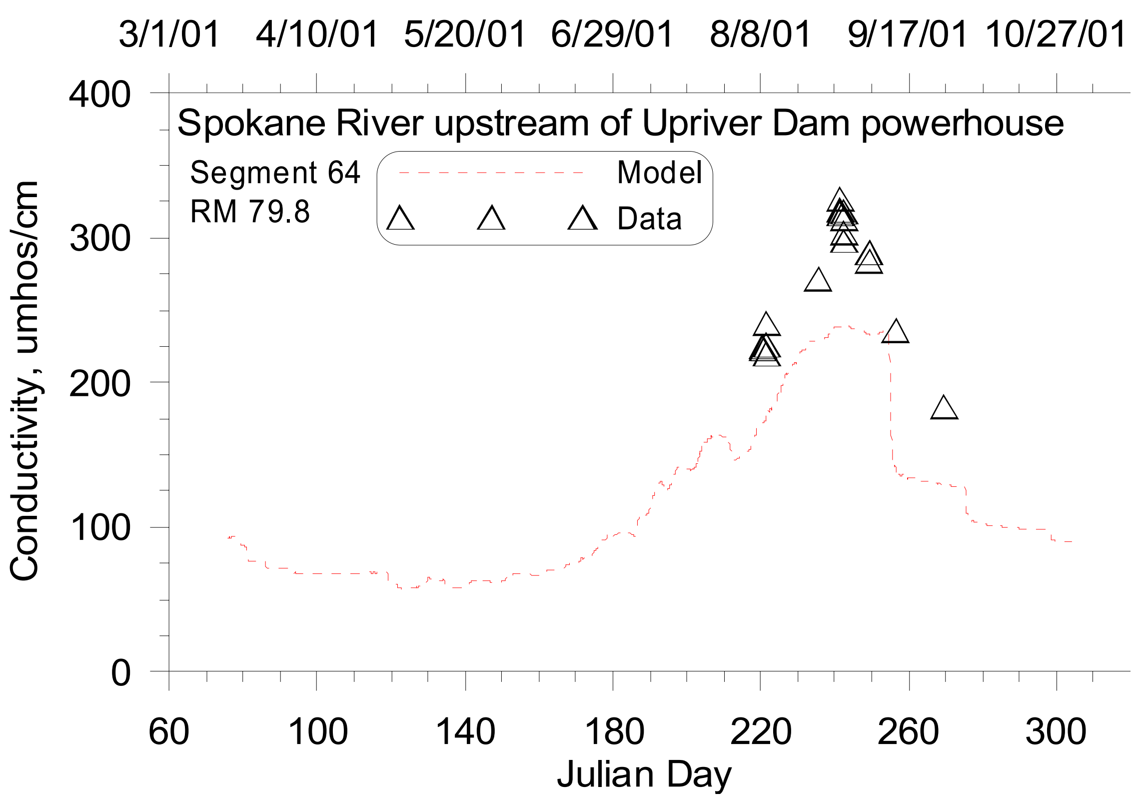

Figure 40. Comparison of model predicted conductivity and data upstream of Upriver Dam powerhouse

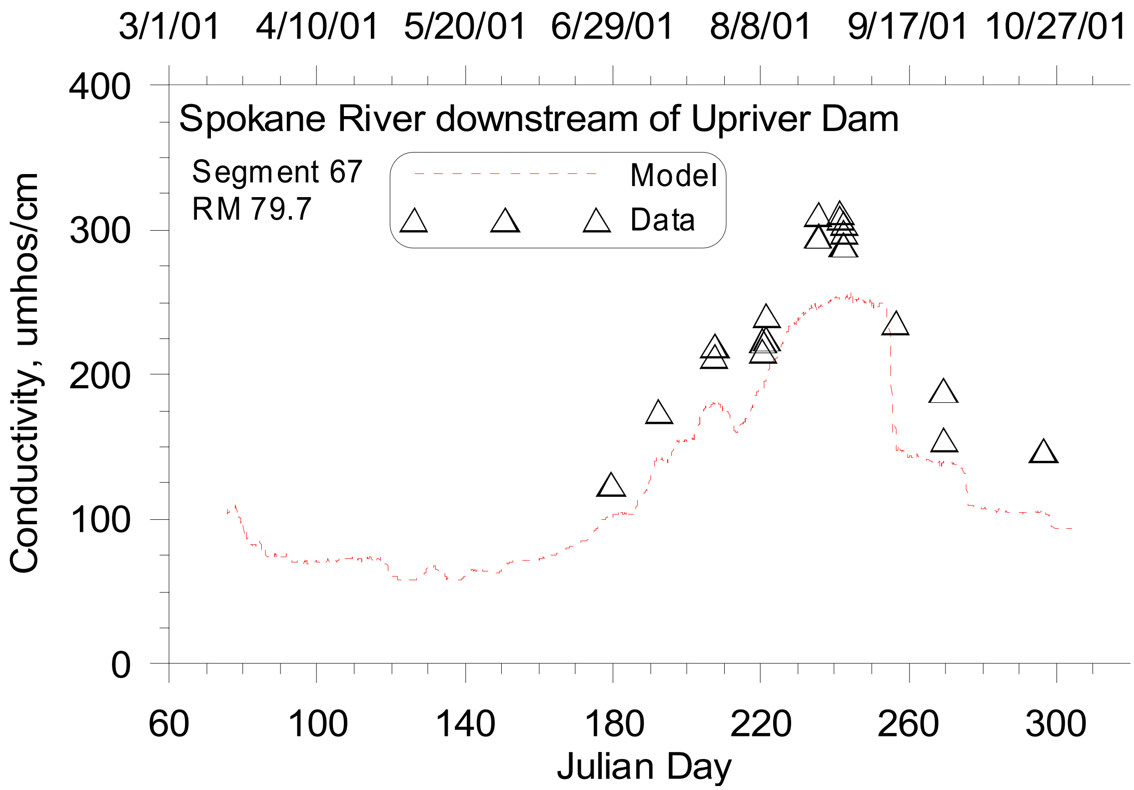

Figure 41. Comparison of model predicted conductivity and data downstream of Upriver Dam

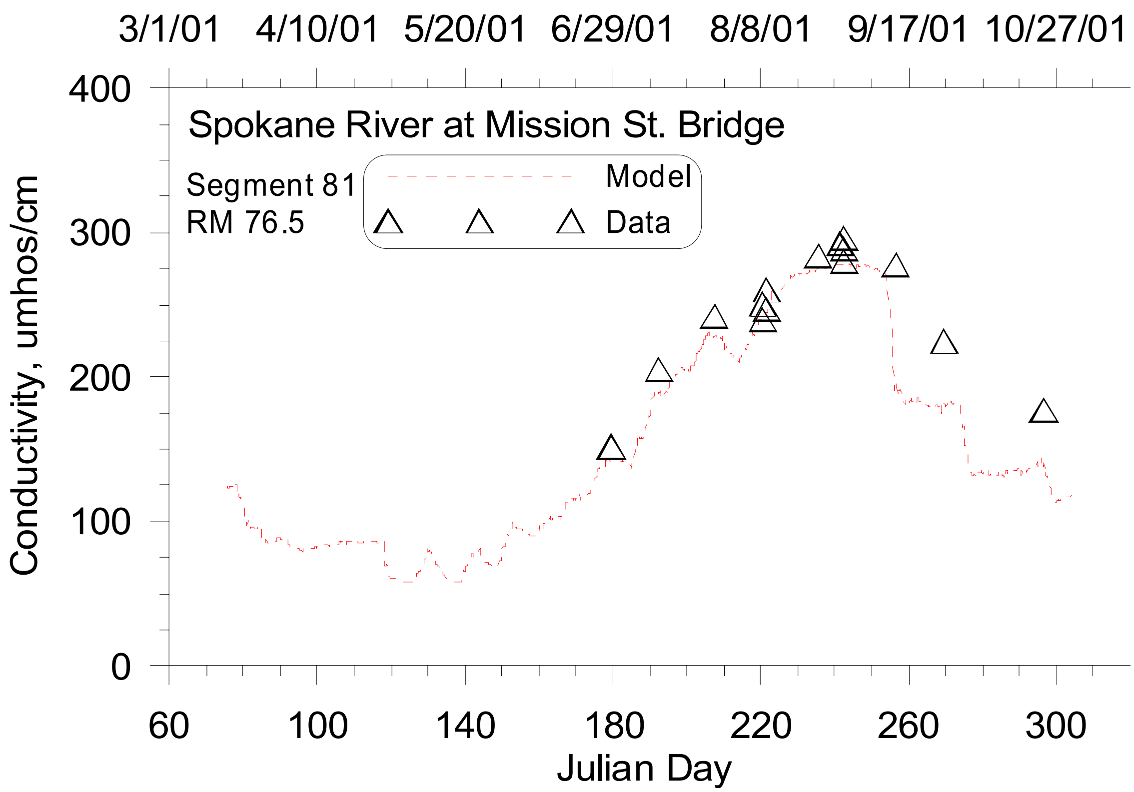

Figure 42. Comparison of model predicted conductivity and data at Mission St. Bridge

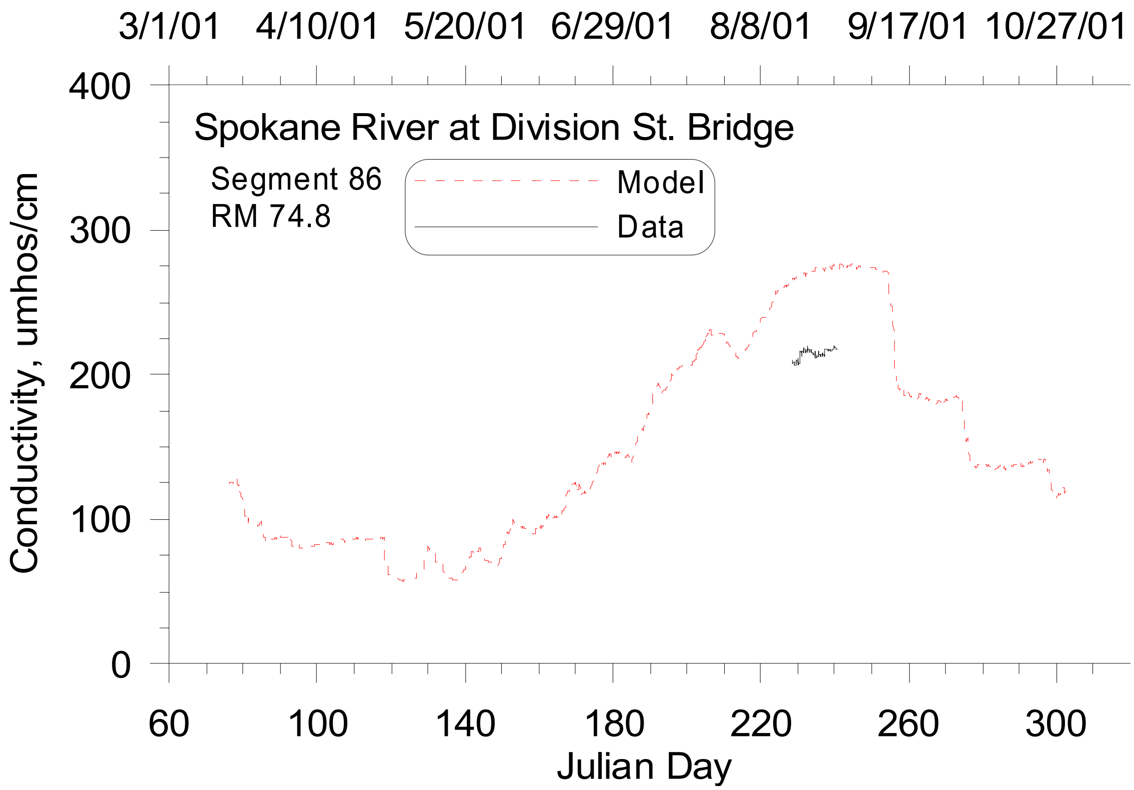

Figure 43. Comparison of model predicted conductivity and data at Division St. Bridge

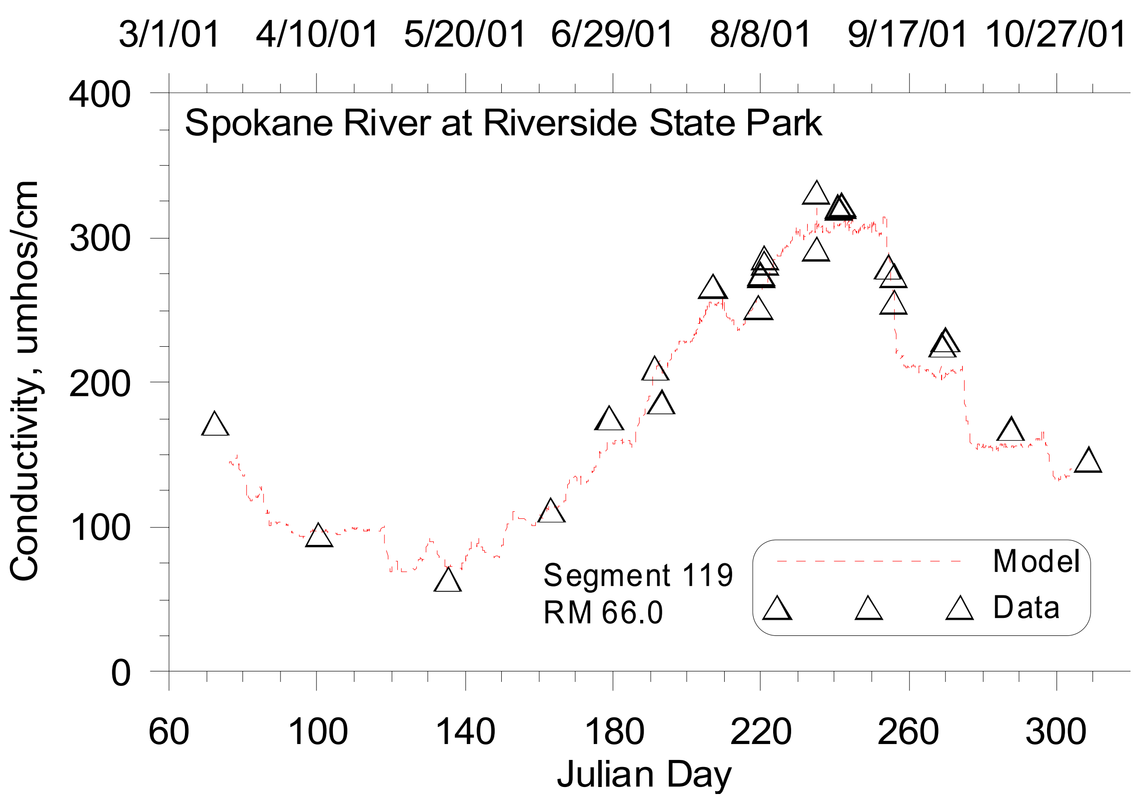

Figure 44. Comparison of model predicted conductivity and data at Riverside State Park

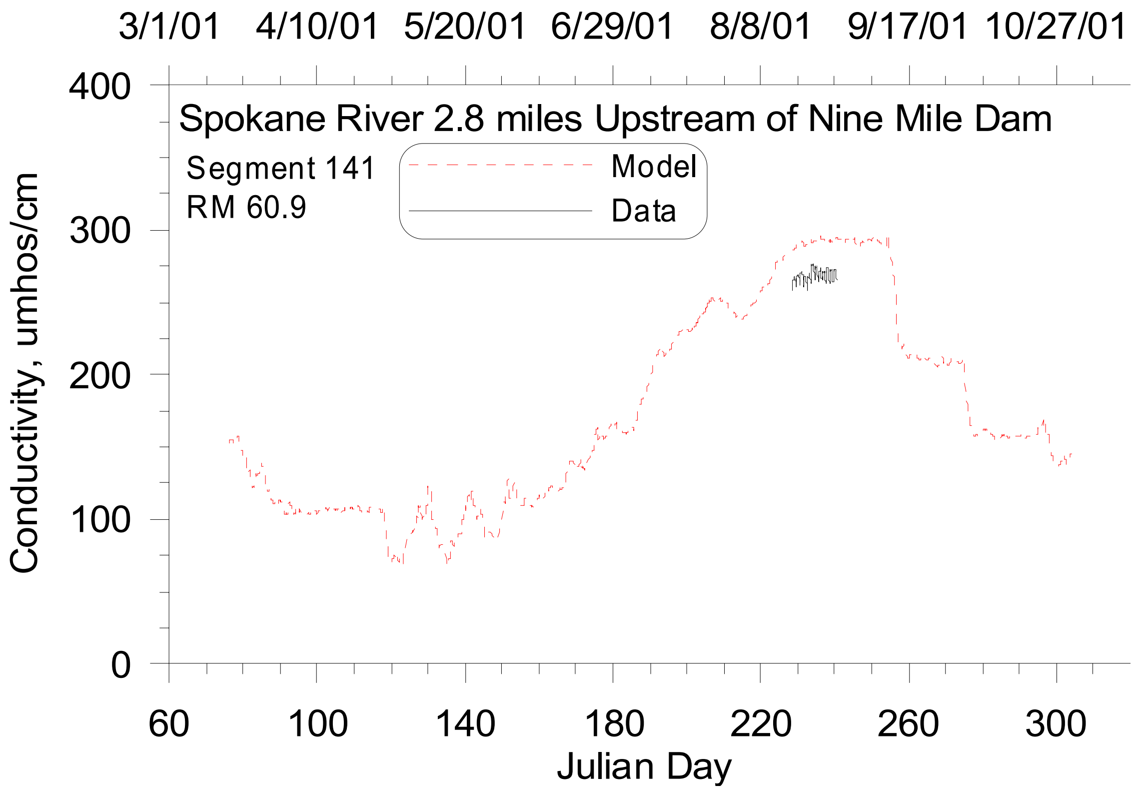

Figure 45. Comparison of model predicted conductivity and data 2.8 miles upstream of Nine Mile Dam

Dissolved Oxygen

CE-QUAL-W2 version 3 permits the use of water body specific reaeration equations. For the riverine section between the state line and Islands Foot Bridge (water body 1), the Melching and Flores (1999) equation applicable to pool and riffle streams was used. A fixed reaeration coefficient of 0.05 d^{-1} was applied to the riverine section between Upper Falls Dam and Seven Mile Bridge. Dissolved oxygen concentrations in this section were frequently supersaturated due to periphyton growth, and a fixed value was required to allow the river to be supersaturated. Downstream of wastewater treatment plant outfalls, surfactants can interfere with the reaeration process causing the reaeration rate coefficient to be reduced from expected theoretical or empirical calculations. For the reservoir sections, the Cole and Buchak (1993) equation was applied. Zero order sediment oxygen demand (SOD) rates were set at 0.6 g m^{-2} d^{-1} for Long Lake Reservoir model segments and 0.1 g m^{-2} d^{-1} for riverine segments. For other reservoir segments, SOD was set between 0.5 g m^{-2} d^{-1} to 0.8 g m^{-2} d^{-1}, with the value 0.8 g m^{-2} d^{-1} applied to the river section immediately above Upriver Dam. Periphyton growth and phytoplankton growth were important factors for simulation of dissolved oxygen. Phytoplankton photosynthesis contributed to elevated dissolved oxygen concentrations near the surface of Long Lake. In riverine section below Upper Falls dam, supersaturated dissolved oxygen concentrations were likely caused by periphyton populations.

CBOD was modeled using separate CBOD groups for each discharger: Liberty WTP, Kaiser Aluminum, Inland Empire and Spokane WTP. This facilitated accurate simulation of the oxygen demand exerted by effluent originating from each discharger since each CBOD group decayed at its own decay rate. CBOD originating from Coulee Creek, Hangman Creek, Little Spokane River, and the upstream boundary condition were modeled as another single CBOD compartment. The first-order decay rates of the

CBOD compartments were developed from laboratory data supplied by the Washington Department of Ecology. Table 19 shows the CBOD decay rates used in the model.

Table 19. Decay rates for each CBOD compartment

CBOD compartment	Description	Decay rate, day^{-1}
1	Liberty WTP	0.0456
2	Kaiser Aluminum	0.1275
3	Inland Empire Paper	0.0186
4	Spokane WTP	0.0736
5	Coulee Creek, Hangman Creek, Little Spokane River, Upstream Boundary Condition	0.0660

Since organic matter originating from point sources and tributaries was modeled with CBOD compartments, the labile dissolved organic matter (LDOM), refractory dissolved organic matter (RDOM), labile particulate organic matter (LPOM), and refractory particulate organic matter (RPOM) compartments only simulated the by-products of phytoplankton and periphyton decay. A decay rate of 0.1 d^{-1} was used for labile dissolved organic matter (LDOM).

Dissolved oxygen profiles were collected in Long Lake in 2001 for 2 days. Figure 46 to Figure 51 show dissolved oxygen profile data and model results for six locations in Long Lake from RM 32.7 to 54.5. Table 20 shows AME and RMS error statistics for the dissolved oxygen vertical profiles. Figure 52 through Figure 57 show model predictions versus data time series at five sites along the Spokane River. Table 21 includes error statistics for the time series comparisons.

Table 20. Dissolved oxygen profile error statistics, 2001

Site	n, # of data profile comparisons	DO model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL0	2	1.60	1.99
LL1	2	1.70	1.96
LL2	2	2.05	2.33
LL3	2	1.68	1.94
LL4	2	1.79	2.25
LL5	2	1.79	2.07

Table 21. Dissolved oxygen time series error statistics, 2001

Site	n, # of data comparisons	DO model –data error statistics	
		AME, mg/L	RMS error, mg/L
SPK60.9	576	1.36	1.64
SPK66.0	12	0.61	0.67
SPK74.8	467	1.94	2.00
SPK76.5	10	1.17	1.20

SPK78.0	5	1.28	1.31
SPK79.7	10	0.77	0.84
SPK79.8	16	1.29	1.61
SPK84.7	3	1.51	1.53

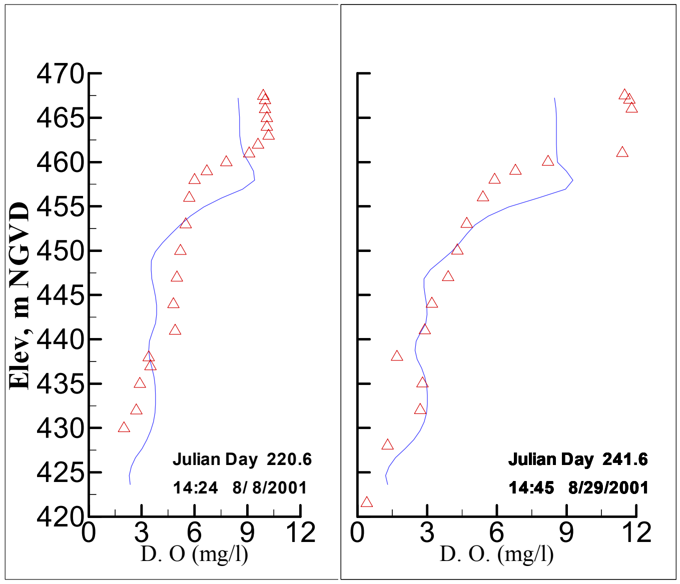

Figure 46. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 0 (Segment 187).

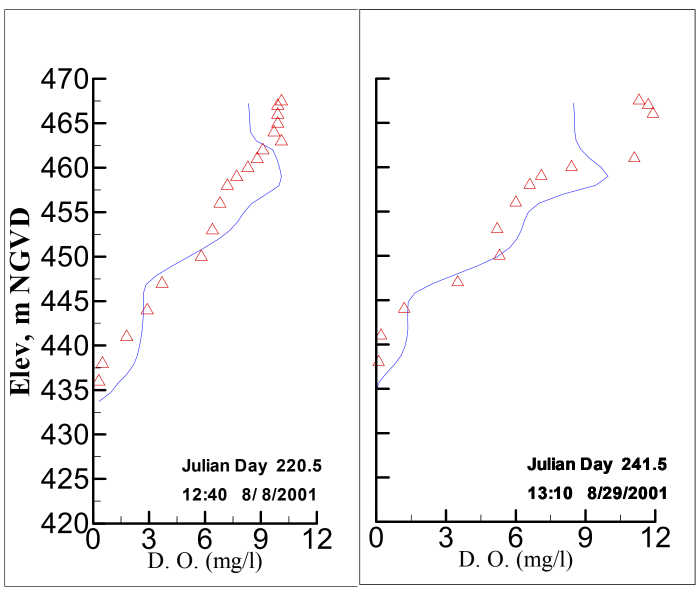

Figure 47. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 1 (Segment 180).

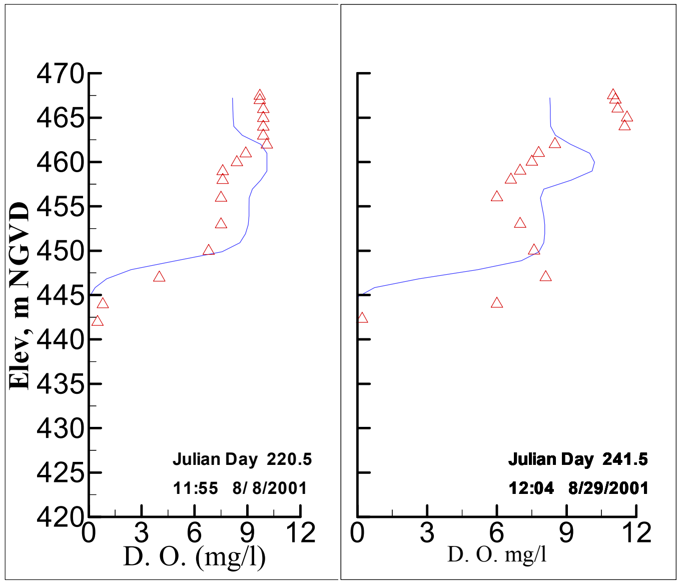

Figure 48. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 2 (Segment 174).

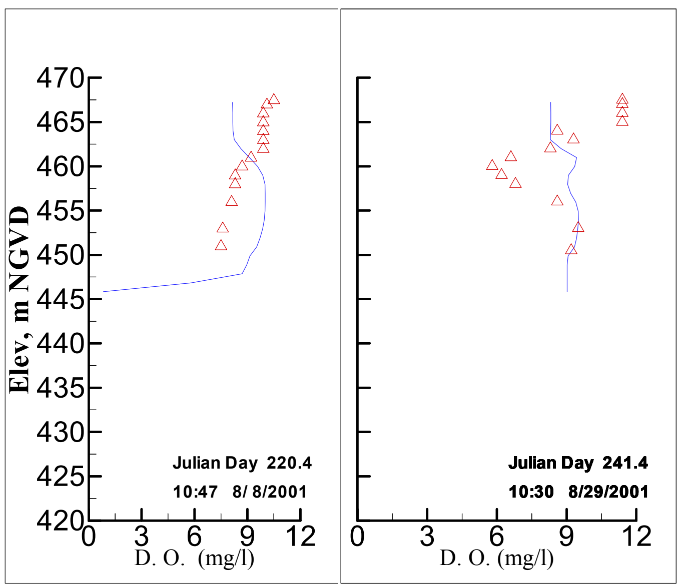

Figure 49. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 3 (Segment 168).

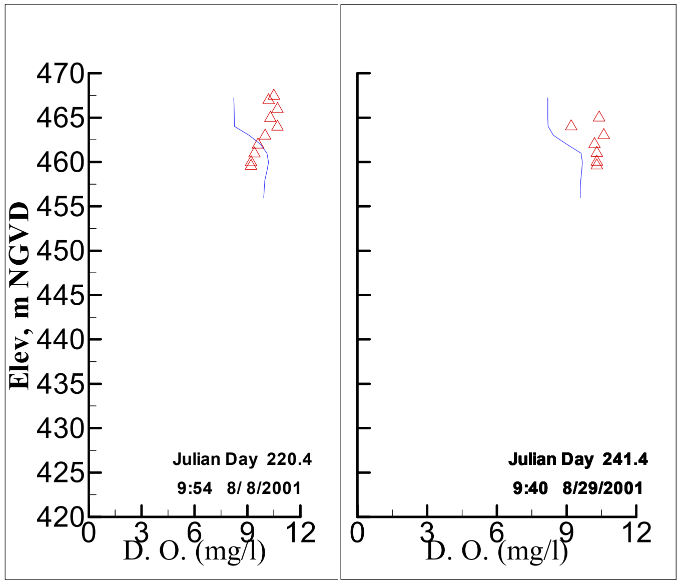

Figure 50. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 4 (Segment 161).

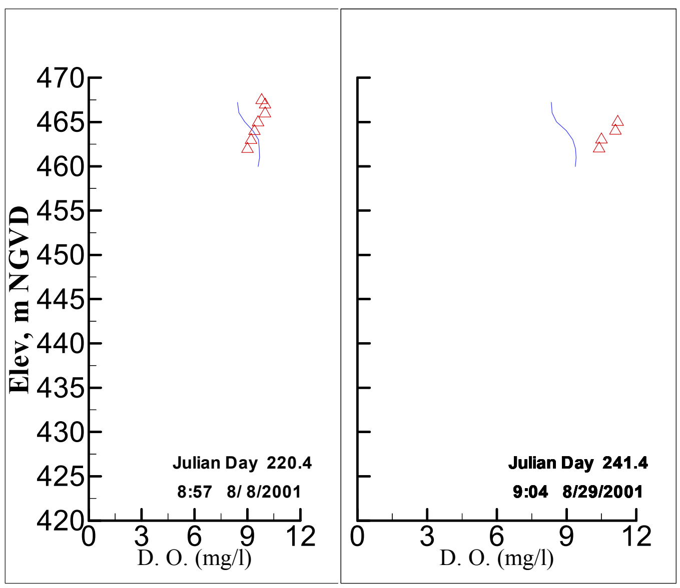

Figure 51. Comparison of model predicted vertical dissolved oxygen profiles and data for Long Lake at Station 5 (Segment 157).

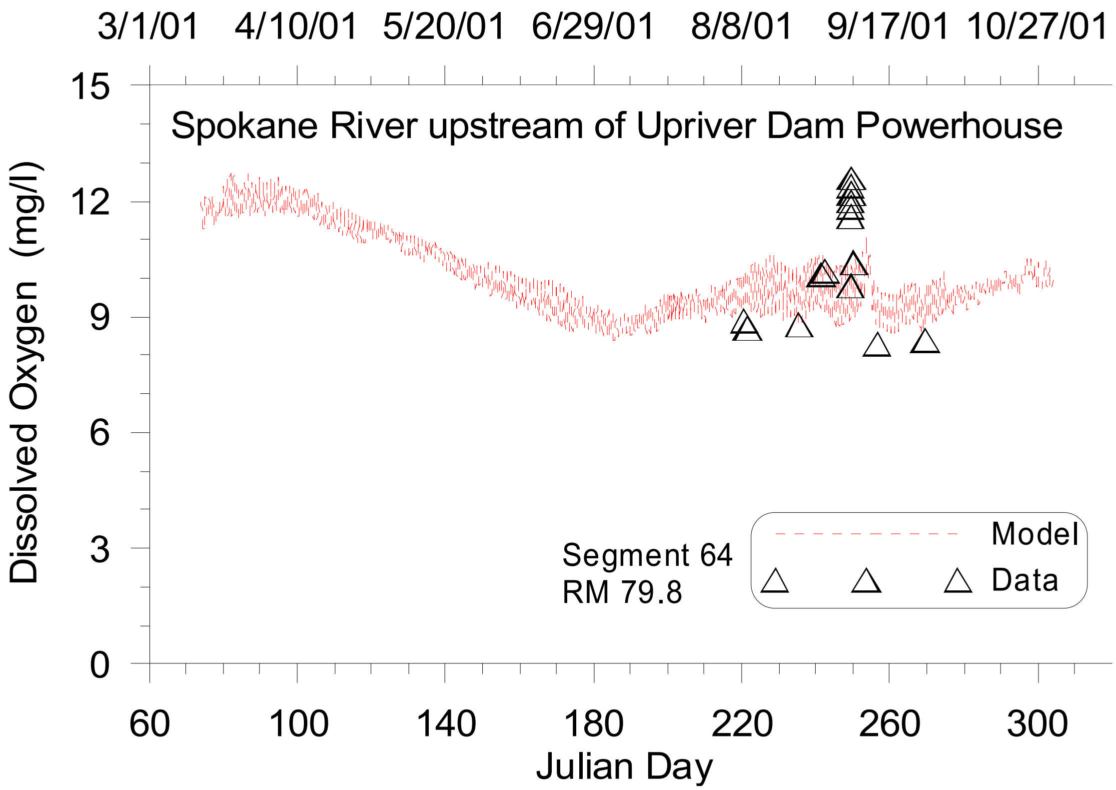

Figure 52. Comparison model predicted dissolved oxygen and data upstream of Upriver Dam powerhouse

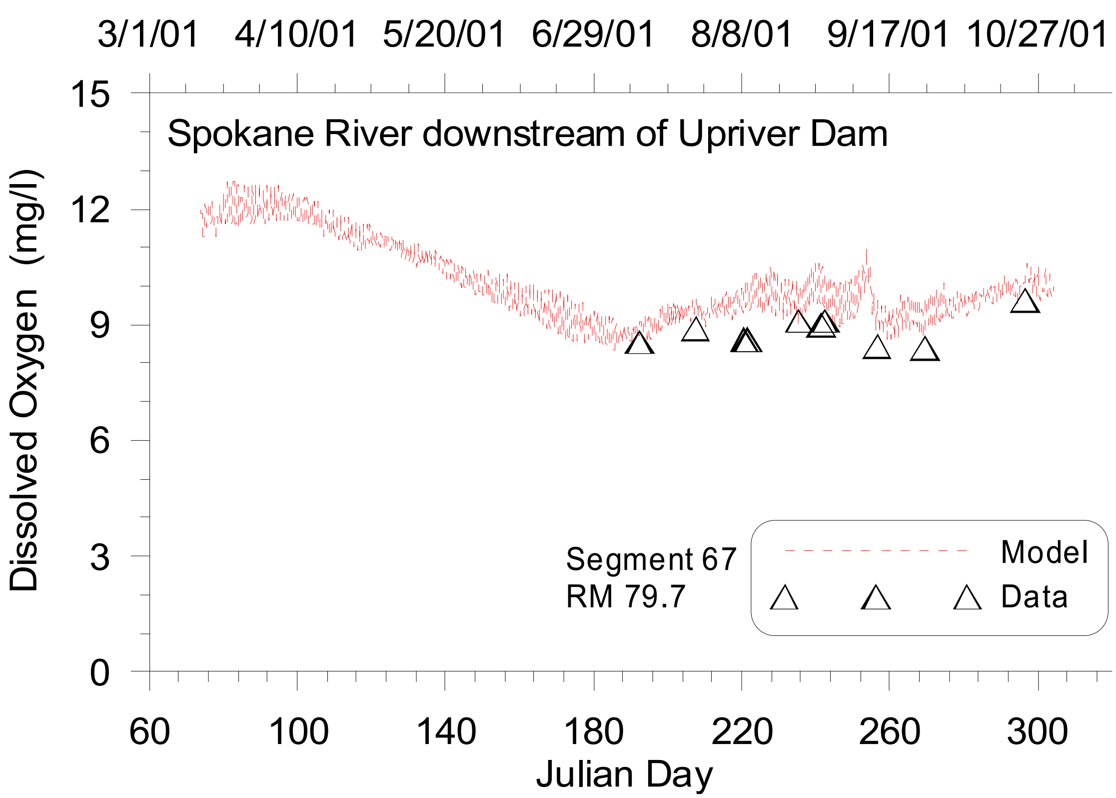

Figure 53. Comparison model predicted dissolved oxygen and data downstream of Upriver Dam

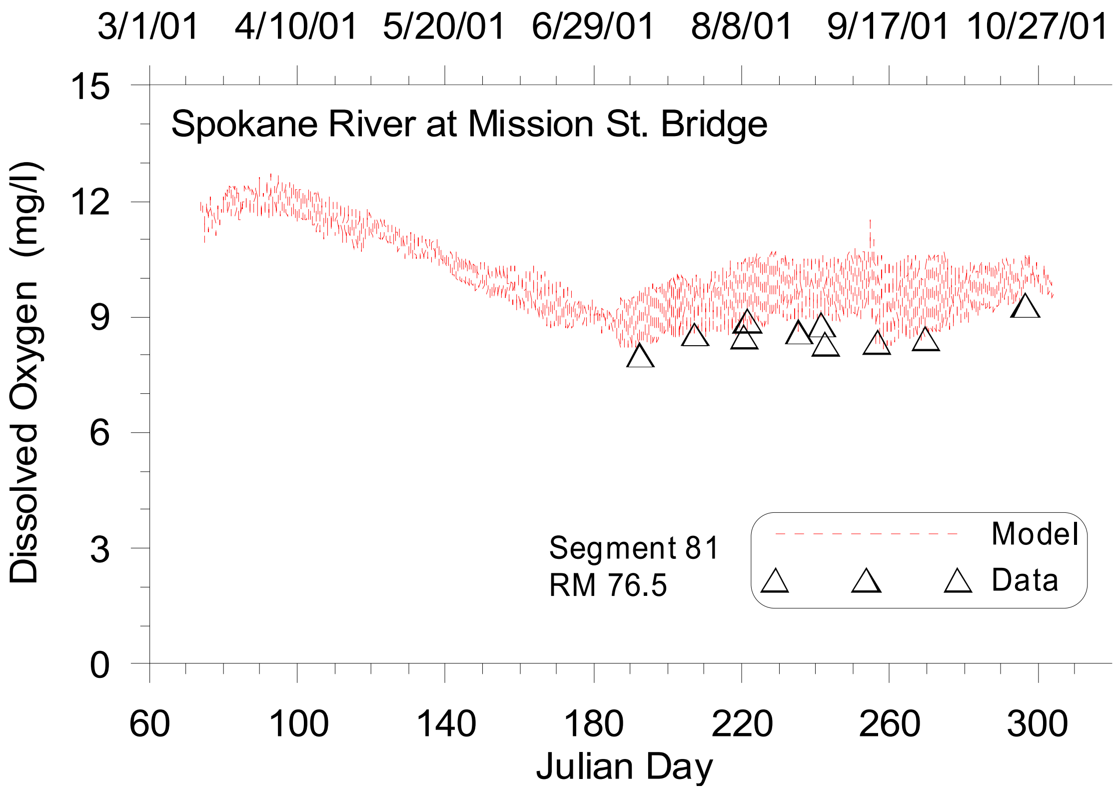

Figure 54. Comparison model predicted dissolved oxygen and data at Mission St. Bridge

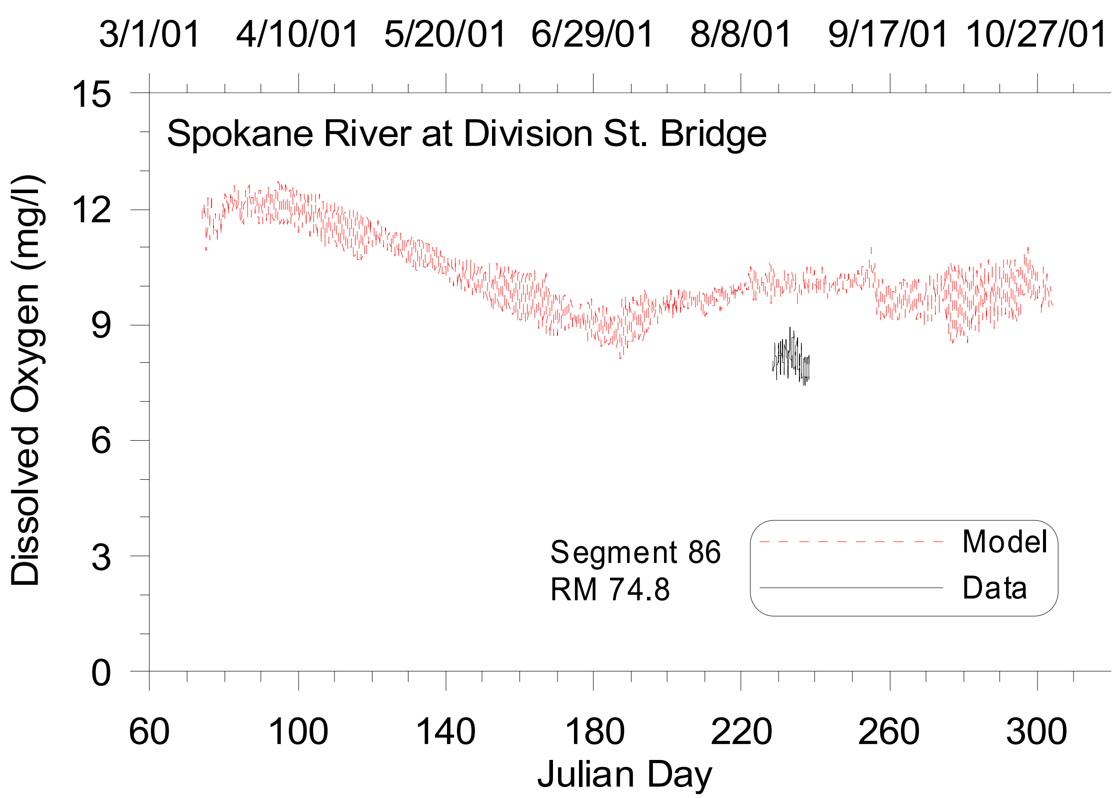

Figure 55. Comparison model predicted dissolved oxygen and data at Division St. Bridge

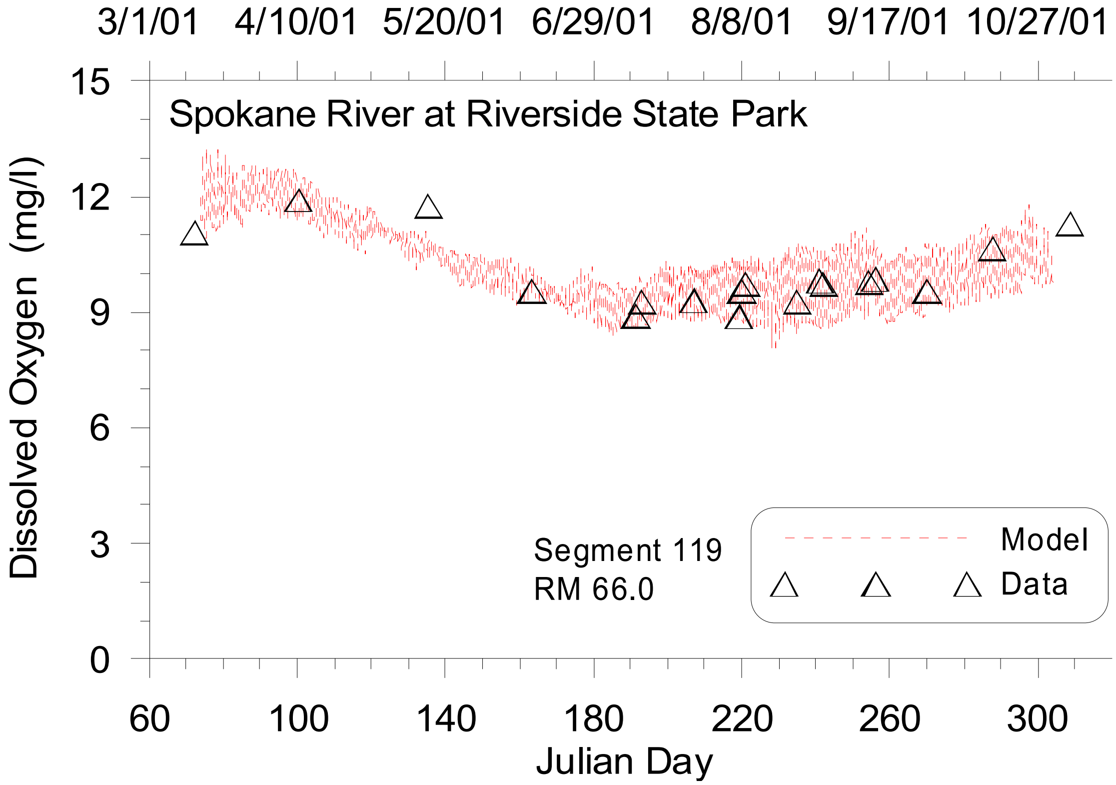

Figure 56. Comparison of model predicted dissolved oxygen and data at Riverside State Park

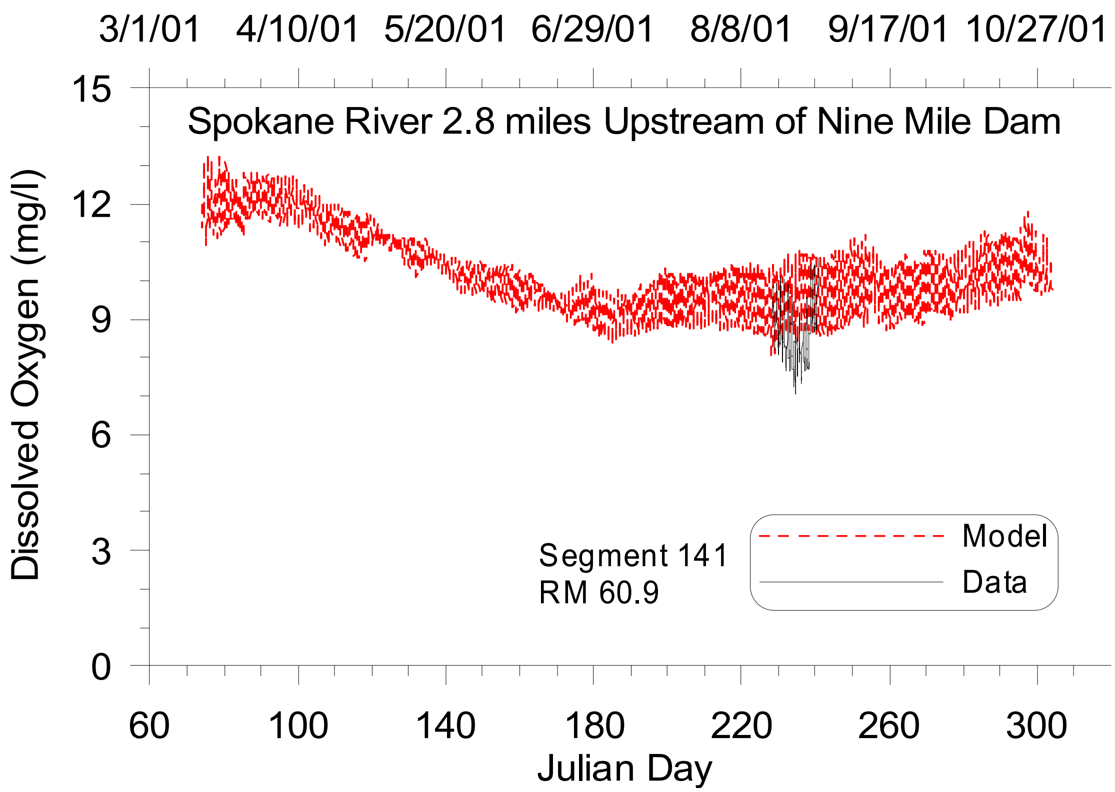

Figure 57. Comparison of model predicted dissolved oxygen and data 2.8 miles upstream of Nine Mile Dam

pH

Vertical pH profiles were collected in Long Lake in 2001 on 2 days. No additional profiles were collected upstream of Long Lake. Figure 58 to Figure 63 show pH profile data and model results for six locations in Long Lake from RM 32.7 to 54.5. Table 22 shows AME and RMS error statistics for the pH vertical profiles. Time series pH model predictions and data are shown in Figure 64 through Figure 68 for five locations along the Spokane River. Table 23 includes the pH model-data error statistics for the seven locations along the Spokane River.

Table 22. pH profile error statistics, 2001

Site	n, # of data profile comparisons	pH model –data error statistics	
		AME	RMS error
LL0	2	0.30	0.33
LL1	2	0.31	0.34
LL2	2	0.34	0.39
LL3	2	0.29	0.34
LL4	2	0.31	0.35
LL5	2	0.48	0.50

Table 23. pH time series error statistics, 2001

Site	n, # of data comparisons	pH model –data error statistics	
		AME	RMS error
SPK66.0	12	0.32	0.40
SPK74.8	580	0.24	0.25
SPK76.5	11	0.30	0.34
SPK78.0	8	0.22	0.26
SPK79.7	11	0.19	0.22
SPK79.8	12	0.27	0.29
SPK84.7	3	0.18	0.19

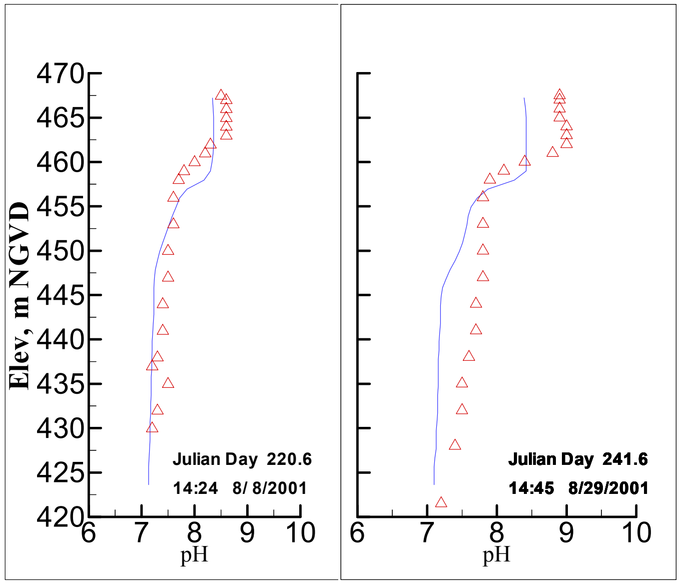

Figure 58. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 0 (Segment 187).

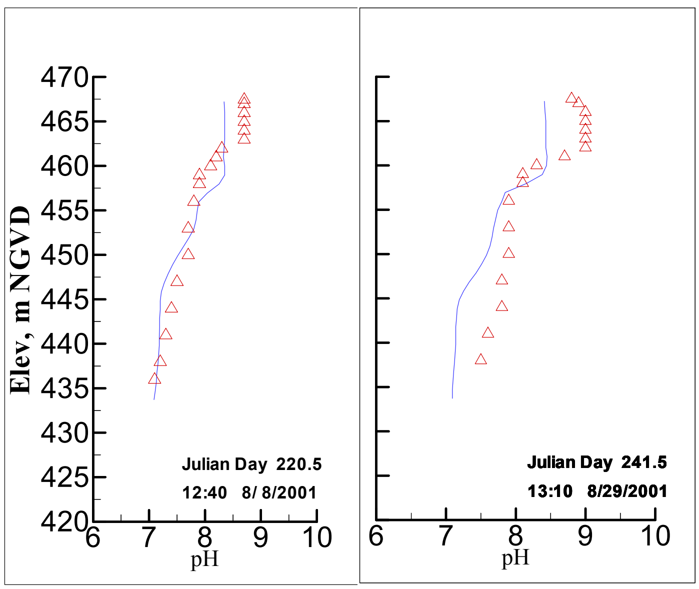

Figure 59. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 1 (Segment 180).

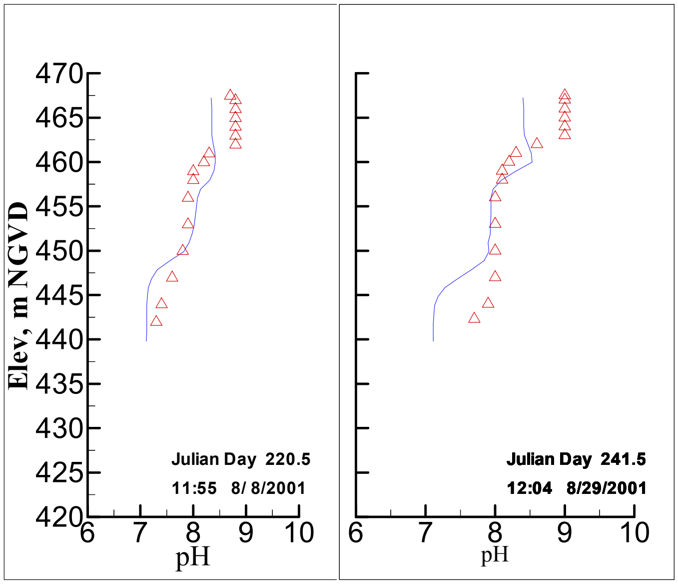

Figure 60. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 2 (Segment 174).

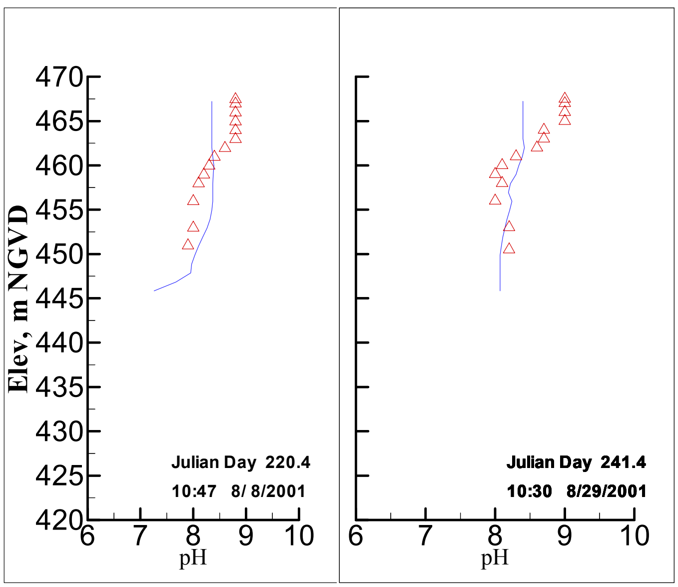

Figure 61. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 3 (Segment 168).

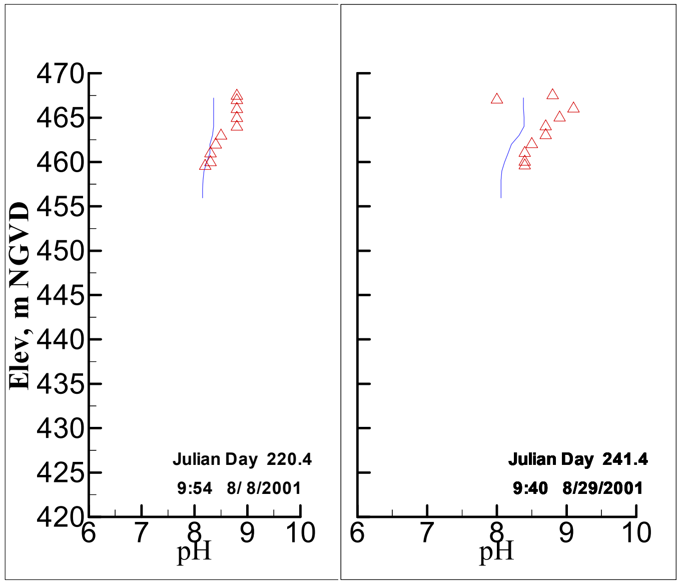

Figure 62. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 4 (Segment 161).

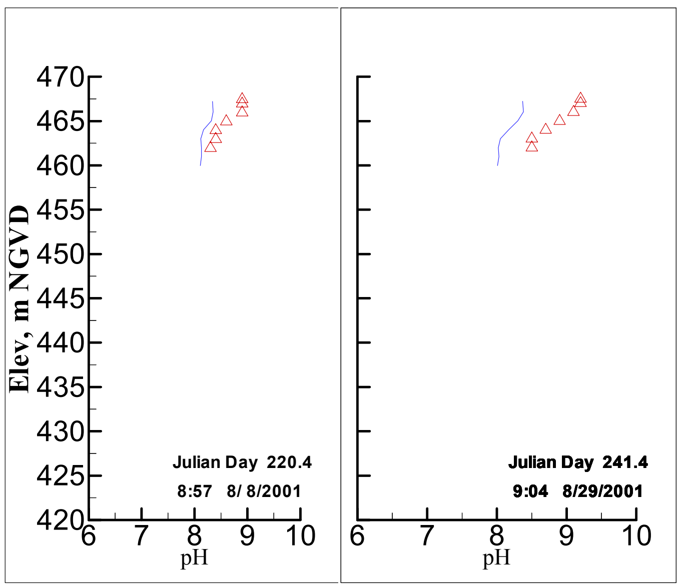

Figure 63. Comparison of model predicted vertical pH profiles and data for Long Lake at Station 5 (Segment 157).

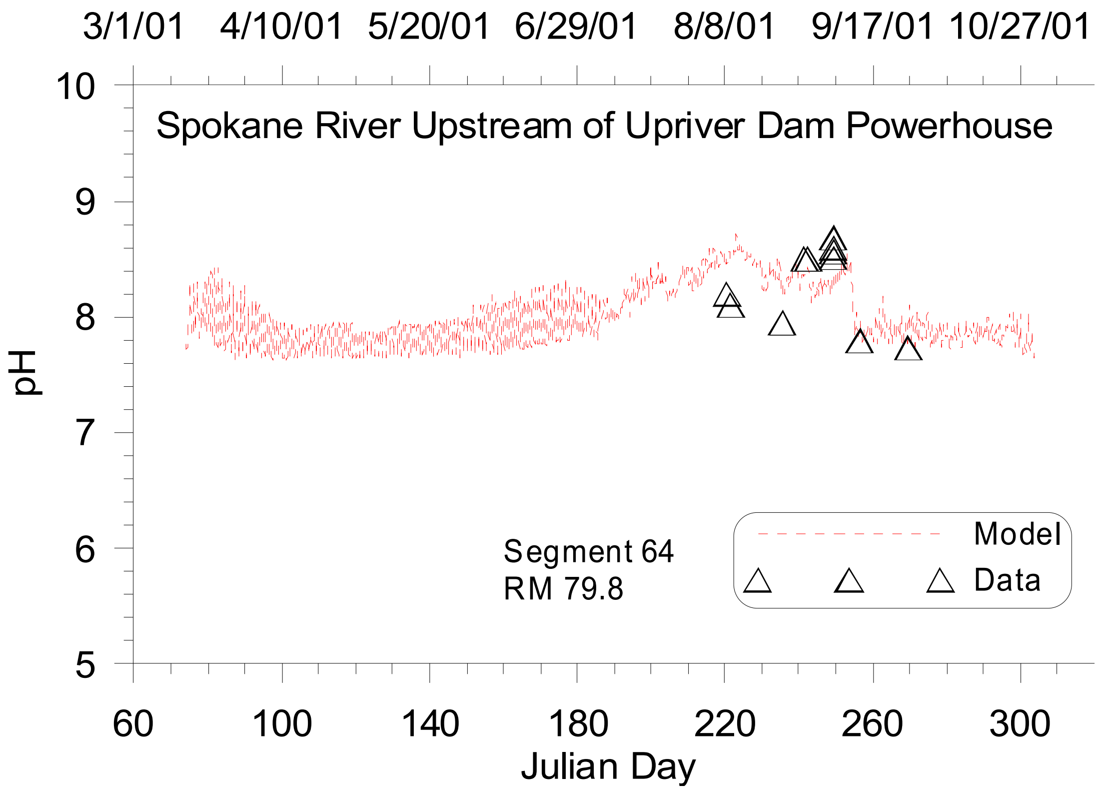

Figure 64. Comparison between model predicted pH and data collected upstream of Upriver Dam

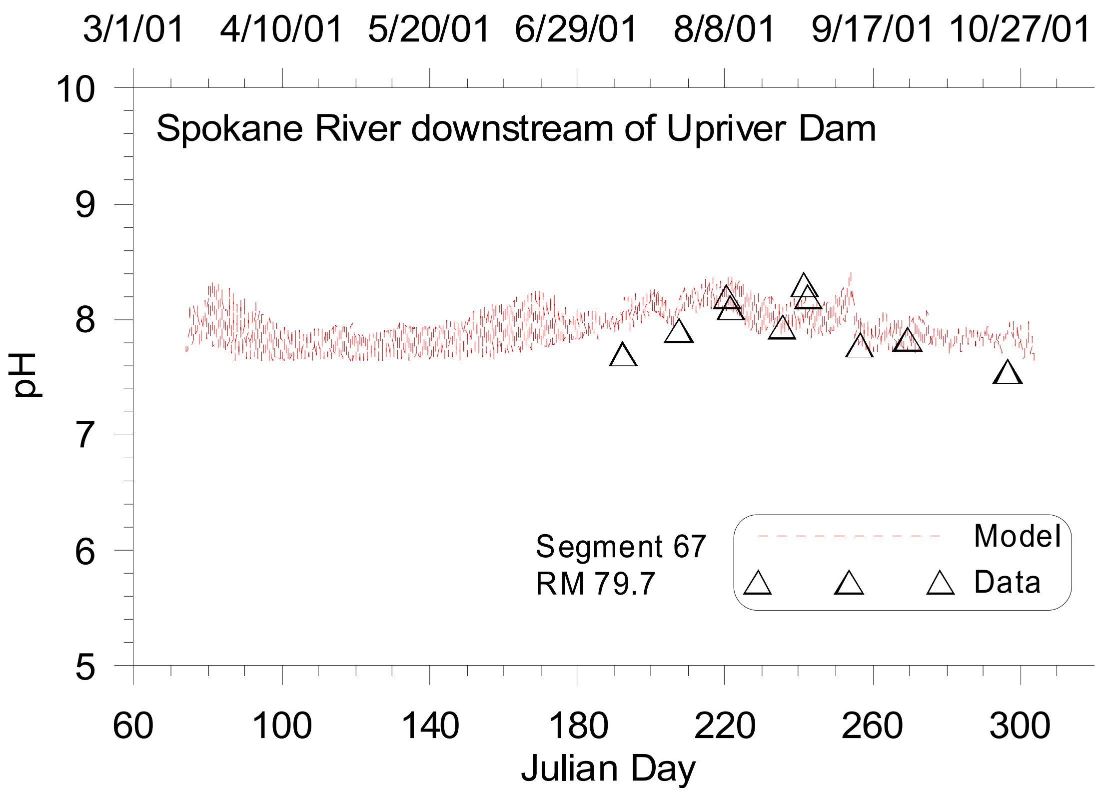

Figure 65. Comparison between model predicted pH and data collected downstream of Upriver Dam

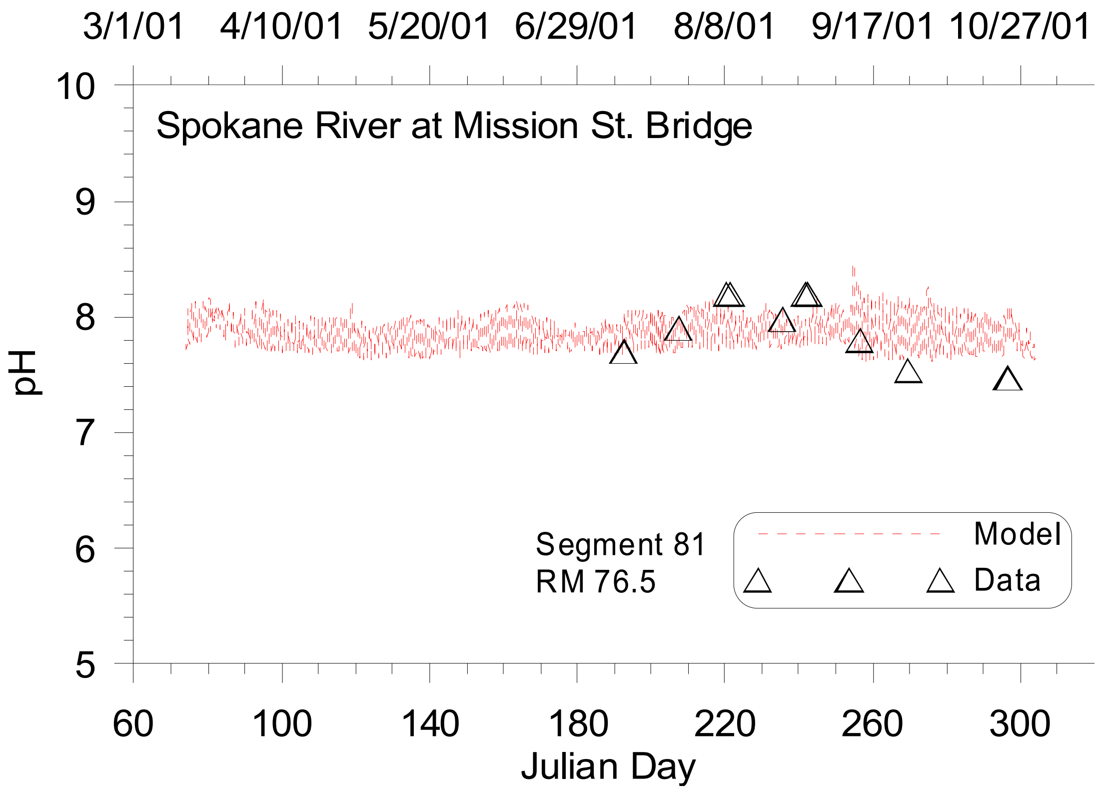

Figure 66. Comparison between model predicted pH and data collected at Mission St. Bridge

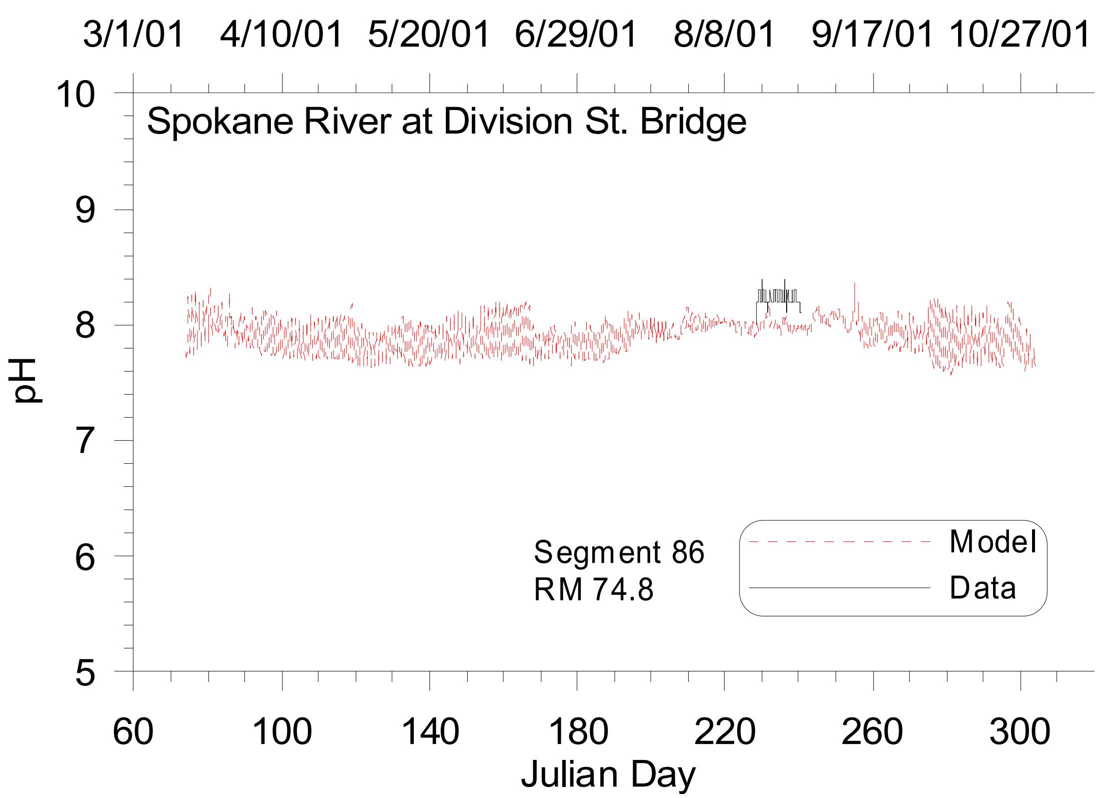

Figure 67. Comparison between model predicted pH and continuous data collected at Division St Bridge

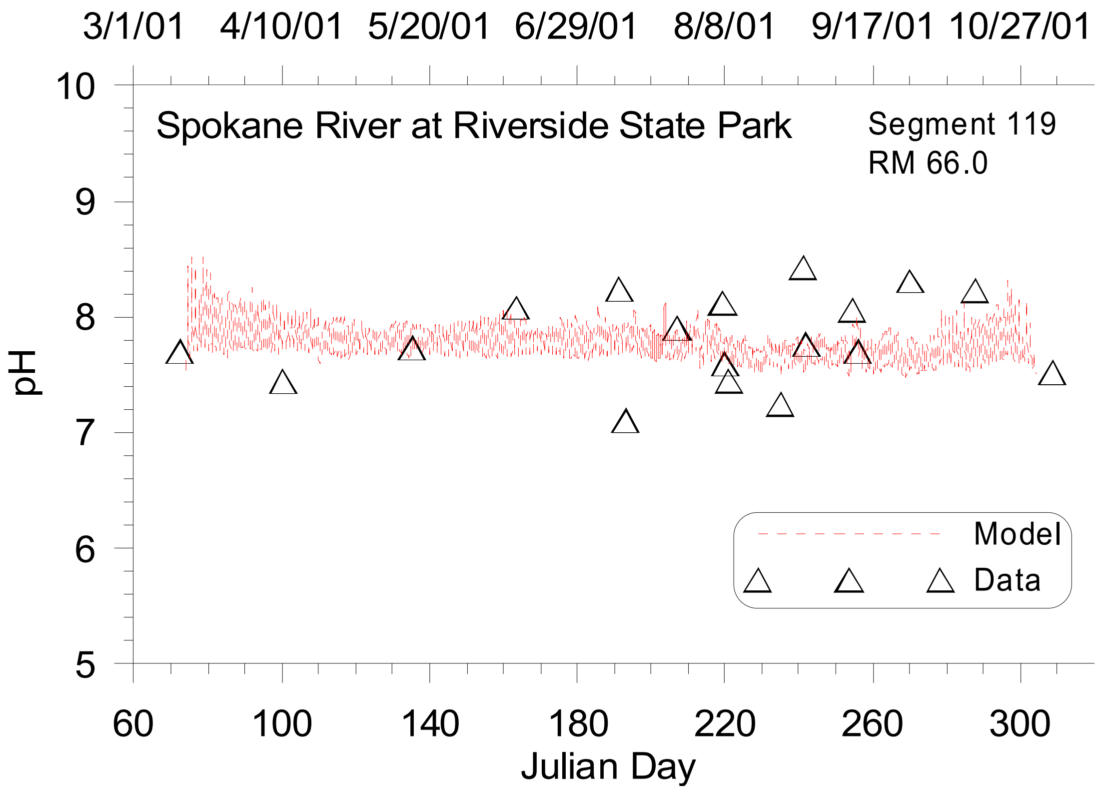

Figure 68. Comparison between model predicted pH and data collected at Riverside State Park

Nitrite-Nitrate Nitrogen

Nitrite-nitrate nitrogen was modeled as a potential source of nitrogen for phytoplankton and periphyton. An ammonia nitrogen preference factor equation was used to predict the amount of nitrite-nitrate nitrogen uptake and ammonia nitrogen uptake of phytoplankton and periphyton.

Nitrite-Nitrate nitrogen vertical profiles were collected in Long Lake in 2001 for 2 days. Figure 69 to Figure 70 show nitrite-nitrate profile data and model results for two locations in Long Lake. Table 24 shows AME and RMS error statistics for the nitrite-nitrate vertical profiles. Figure 71 to Figure 73 show nitrite-nitrate time series data compared with model results three locations along the Spokane River. Table 25 includes nitrite-nitrate model-data error statistics for five time series comparisons.

Table 24. Nitrite-Nitrate Nitrogen profile error statistics, 2001

Site	n, # of data profile comparisons	NO2-NO3-N model –data error statistics	
		AME, mg/L	RMS, mg/L
LL1	2	0.26	0.35
LL3	2	0.52	0.60

Table 25. Nitrite-Nitrate Nitrogen time series error statistics, 2001

Site	n, # of data comparisons	NO2-NO3-N model –data error statistics

		AME, mg/L	RMS error, mg/L
SPK66.0	22	0.30	0.38
SPK76.5	11	0.09	0.12
SPK79.7	14	0.11	0.13
SPK79.8	2	0.28	0.28
SPK84.7	6	0.27	0.28

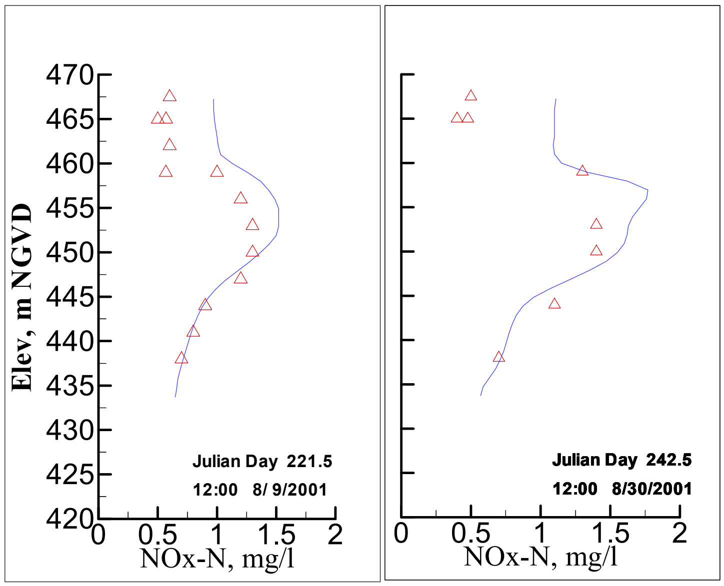

Figure 69. Comparison of model predicted vertical nitrite-nitrate nitrogen profiles and data for Long Lake at Station 1 (Segment 180).

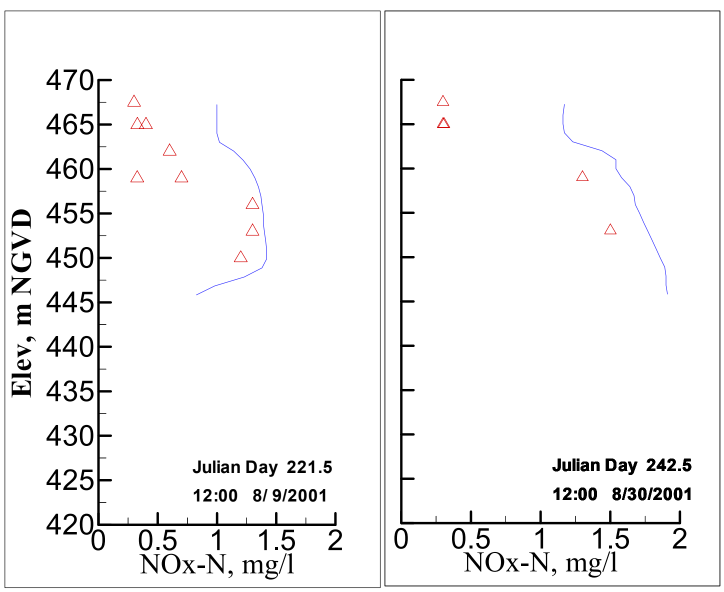

Figure 70. Comparison of model predicted vertical nitrite-nitrate nitrogen profiles and data for Long Lake at Station 3 (Segment 168).

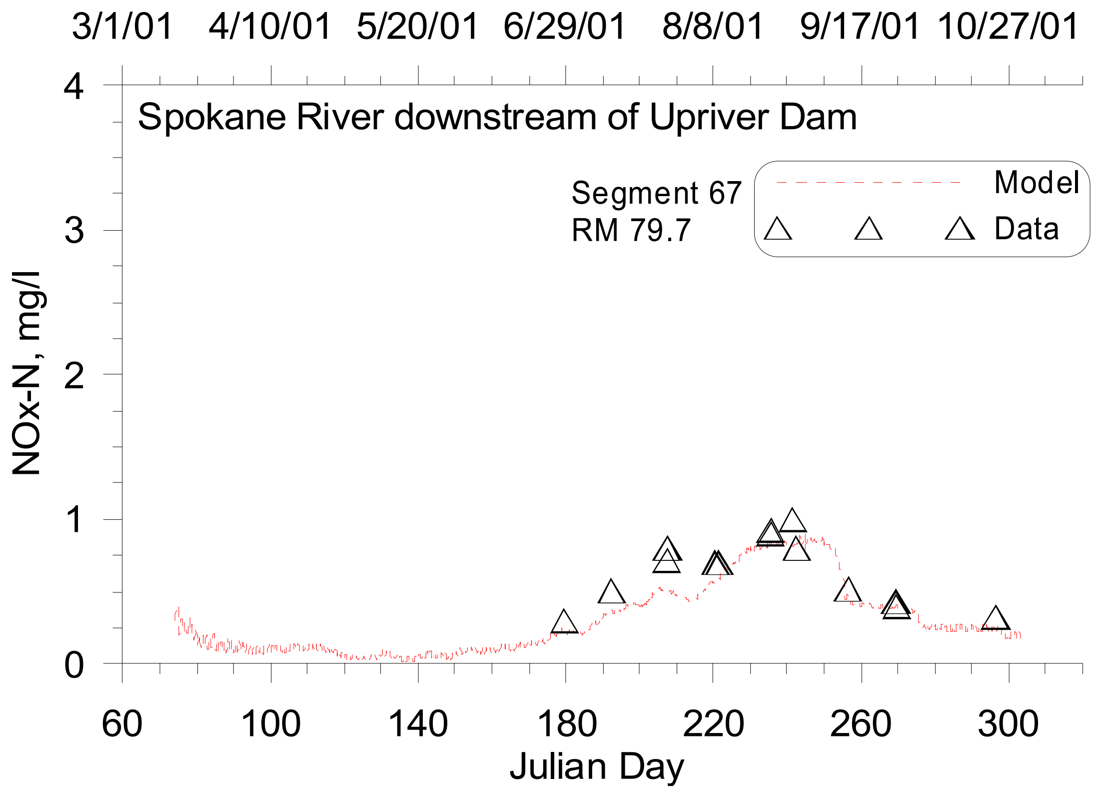

Figure 71. Comparison of model predicted nitrite-nitrate nitrogen and data downstream of Upriver Dam

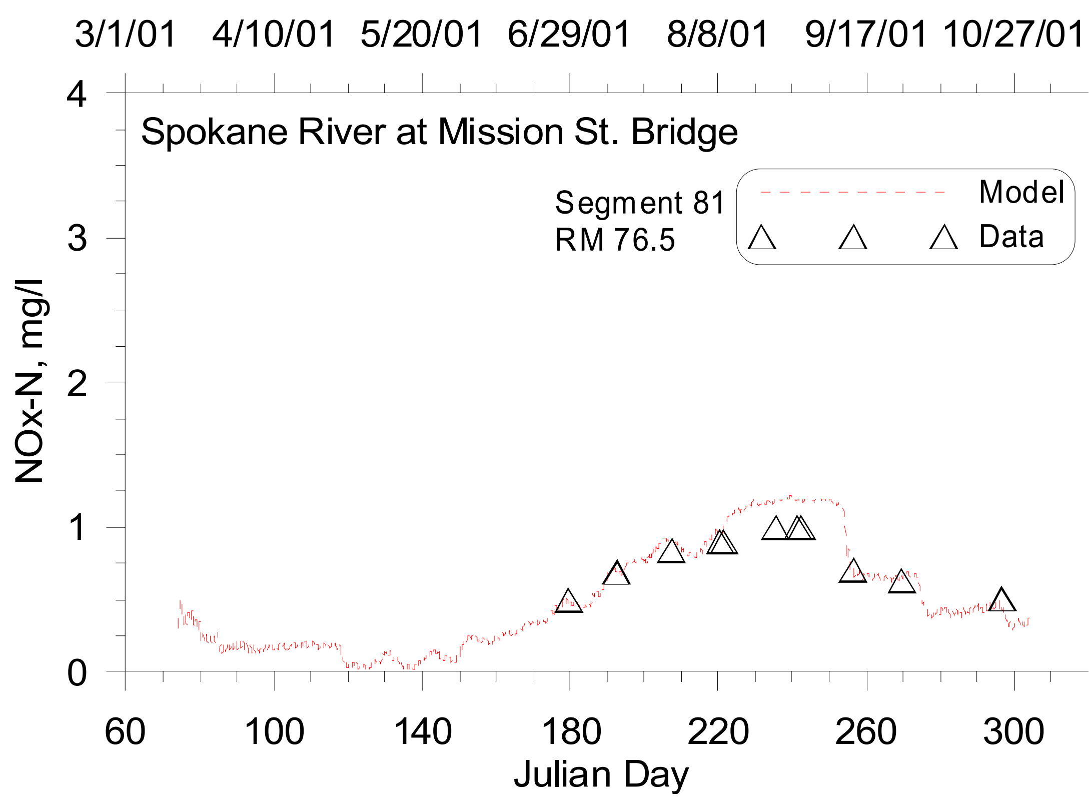

Figure 72. Comparison of model predicted nitrite-nitrate nitrogen and data at Mission St. Bridge

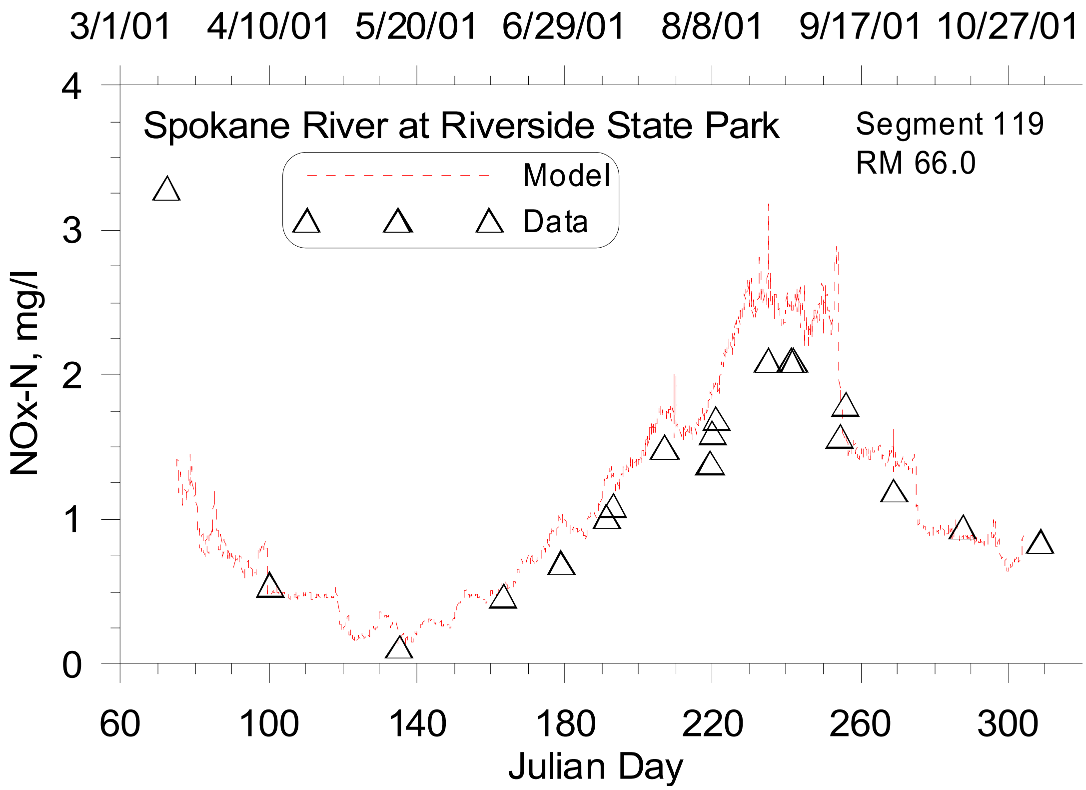

Figure 73. Comparison of model predicted nitrite-nitrate nitrogen and data at Riverside State Park

Ammonia Nitrogen

Ammonia nitrogen vertical profiles were collected in Long Lake in 2001 for 2 days. Figure 74 and Figure 75 show ammonia nitrogen profile data and model results for sample sites LL1 and LL3. Table 26 shows AME and RMS error statistics for the ammonia nitrogen vertical profiles. Figure 76 shows ammonia nitrogen time series mode data comparison at RM 76.5, the Mission St. Bridge. Figure 77 shows ammonia nitrogen time series data compared with model results for RM 66. Figure 78 shows ammonia nitrogen time series data compared with model results for a shorter time period at the same site. Table 27 includes ammonia nitrogen model-data error statistics for five time series comparisons.

Table 26. Ammonia Nitrogen profile error statistics, 2001

Site	n, # of data profile comparisons	NH4-N model –data error statistics	
		AME, mg/L	RMS, mg/L
LL1	2	0.006	0.006
LL3	2	0.011	0.015

Table 27. Ammonia Nitrogen time series error statistics, 2001

Site	n, # of data comparisons	NH4-N model –data error statistics	
		AME, mg/L	RMS error, mg/L

SPK66.0	14	0.05	0.09
SPK76.5	6	0.07	0.08
SPK79.7	6	0.19	0.34
SPK79.8	2	0.01	0.01
SPK84.7	2	0.05	0.06

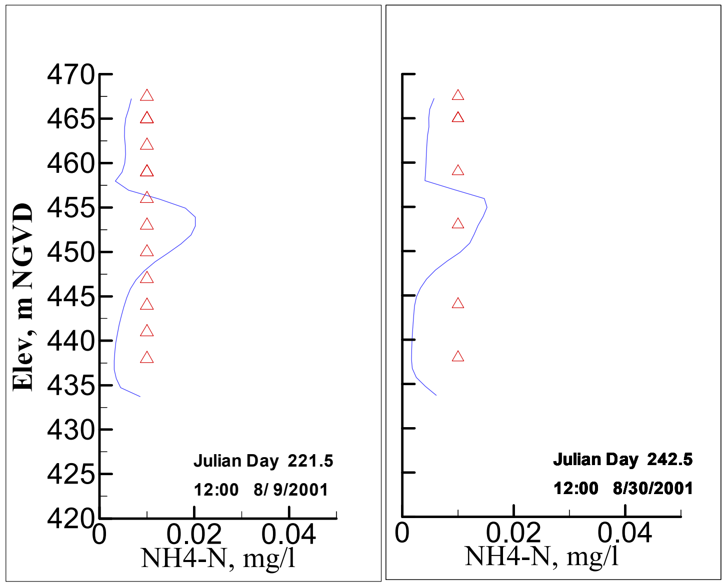

Figure 74. Comparison of model predicted vertical ammonia profiles and data for Long Lake at Station 1 (Segment 180).

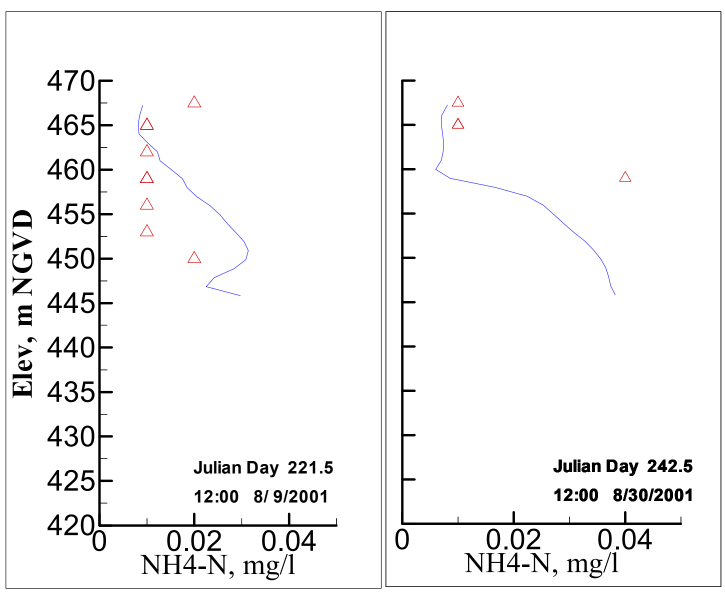

Figure 75. Comparison of model predicted vertical ammonia nitrogen profiles and data for Long Lake at Station 3 (Segment 168).

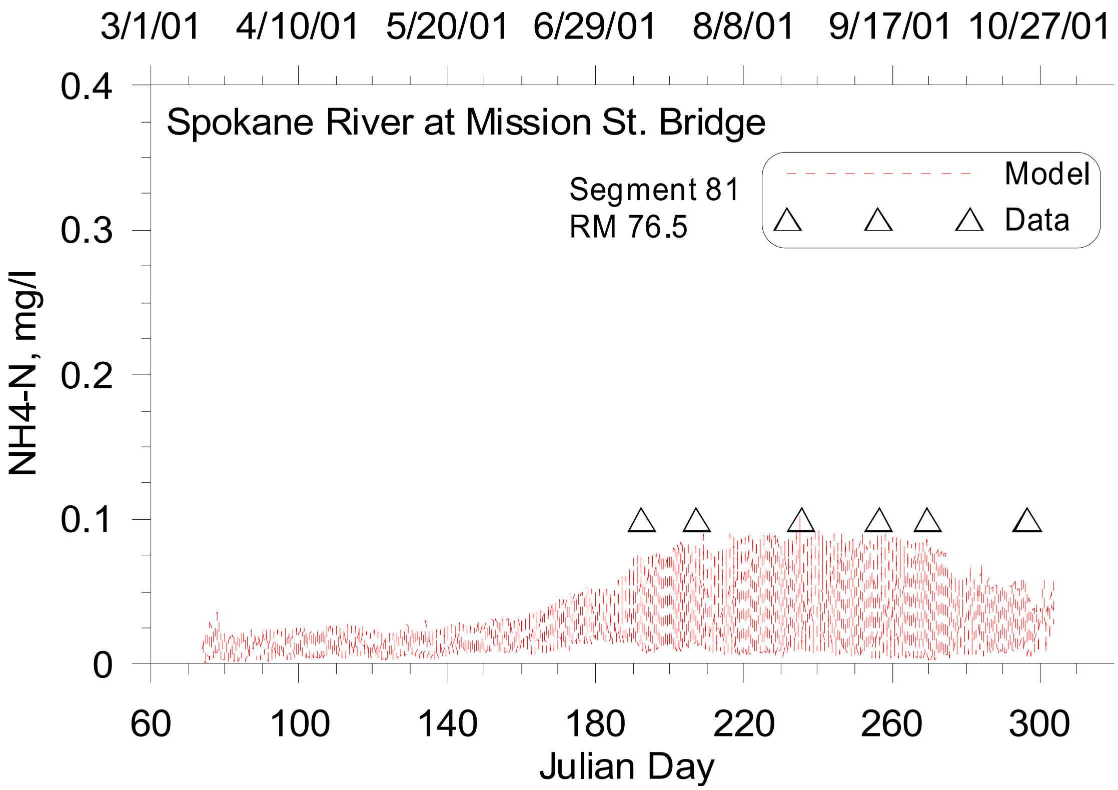

Figure 76. Comparison of model predicted ammonia nitrogen and data at Mission St. Bridge

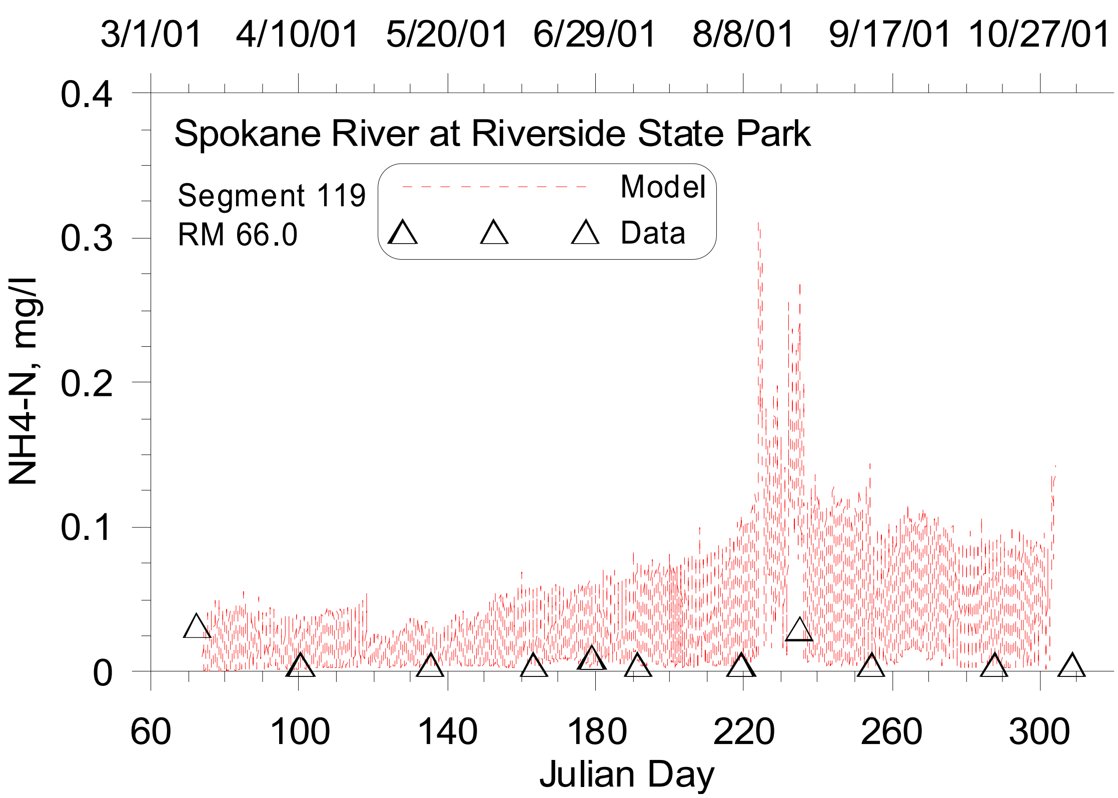

Figure 77. Comparison of model predicted ammonia nitrogen and data for at Riverside State Park

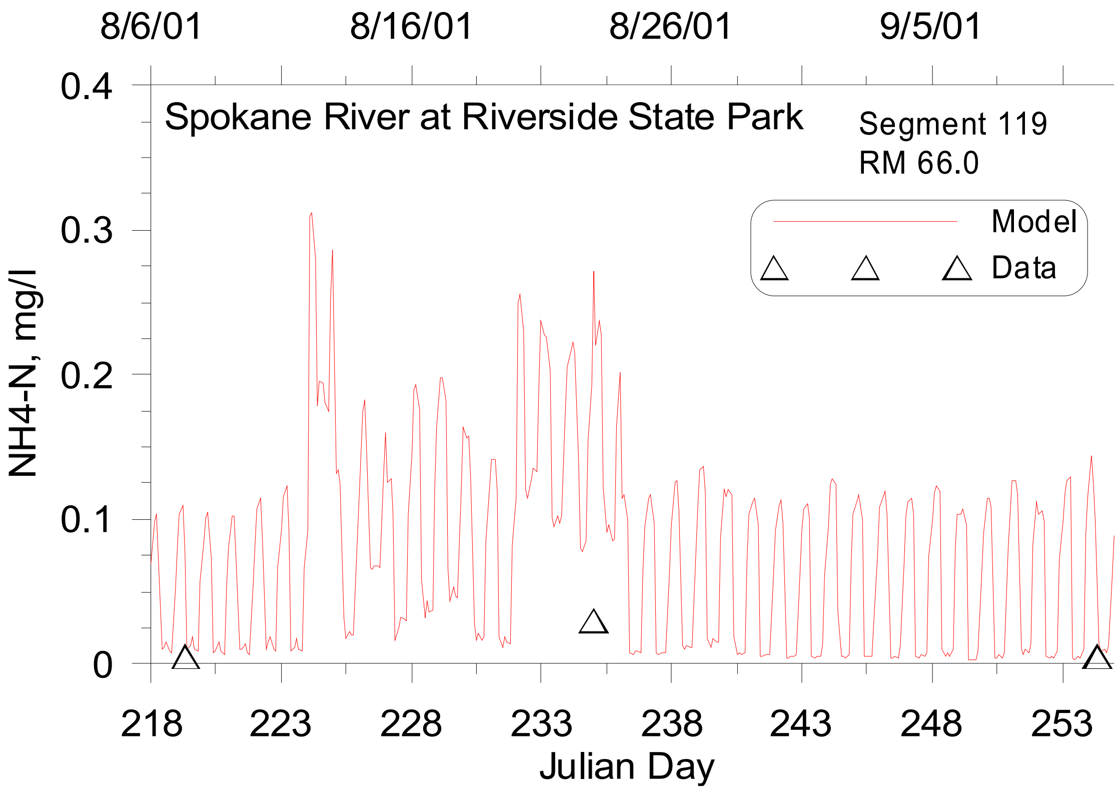

Figure 78. A shorter period comparison of model predicted ammonia nitrogen and data at Riverside State illustrating the diurnal fluctuations.

Soluble Reactive Phosphorus

Soluble reactive phosphorus (SRP) vertical profiles were collected in Long Lake in 2001 for 2 days. No additional vertical profiles were collected upstream of Long Lake. Figure 79 and Figure 80 show SRP vertical profile data and model results for sample site LL1 and LL3 in Long Lake. Table 28 shows AME and RMS error statistics for the SRP vertical profiles. Figure 81 to Figure 83 show SRP time series data compared with model results for three sites along the Spokane River. Table 29 includes SRP model-data error statistics for five time series comparisons.

Table 28. Soluble Reactive Phosphorus profile error statistics, 2001

Site	n, # of data profile comparisons	SRP model –data error statistics	
		AME, mg/L	RMS, mg/L
LL1	2	0.007	0.010
LL3	2	0.003	0.004

Table 29. Soluble Reactive Phosphorus time series error statistics, 2001

Site	n, # of data comparisons	SRP model –data error statistics	
		AME, mg/L	RMS error, mg/L
SPK66.0	20	0.003	0.003

SPK76.5	10	0.003	0.005
SPK79.7	12	0.003	0.004
SPK79.8	2	0.002	0.002
SPK84.7	4	0.004	0.006

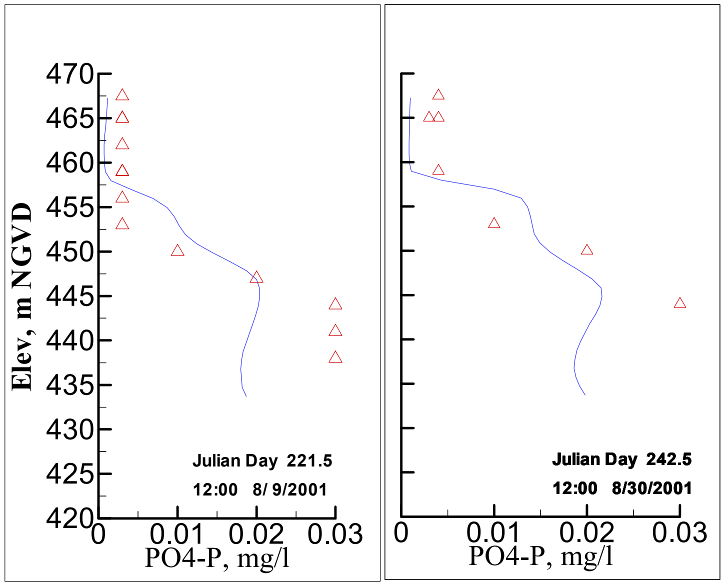

Figure 79. Comparison of model predicted vertical soluble reactive phosphorus profiles and data for Long Lake at Station 1 (Segment 180).

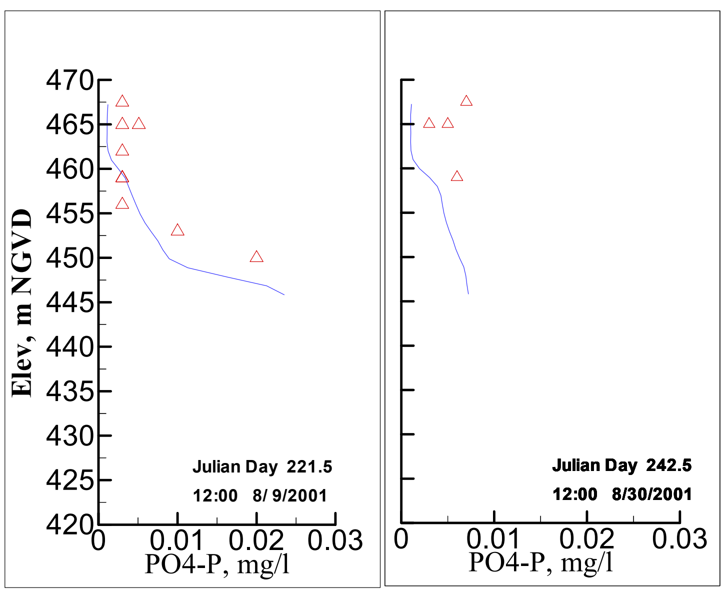

Figure 80. Comparison of model predicted vertical soluble reactive phosphorus profiles and data for Long Lake at Station 3 (Segment 168).

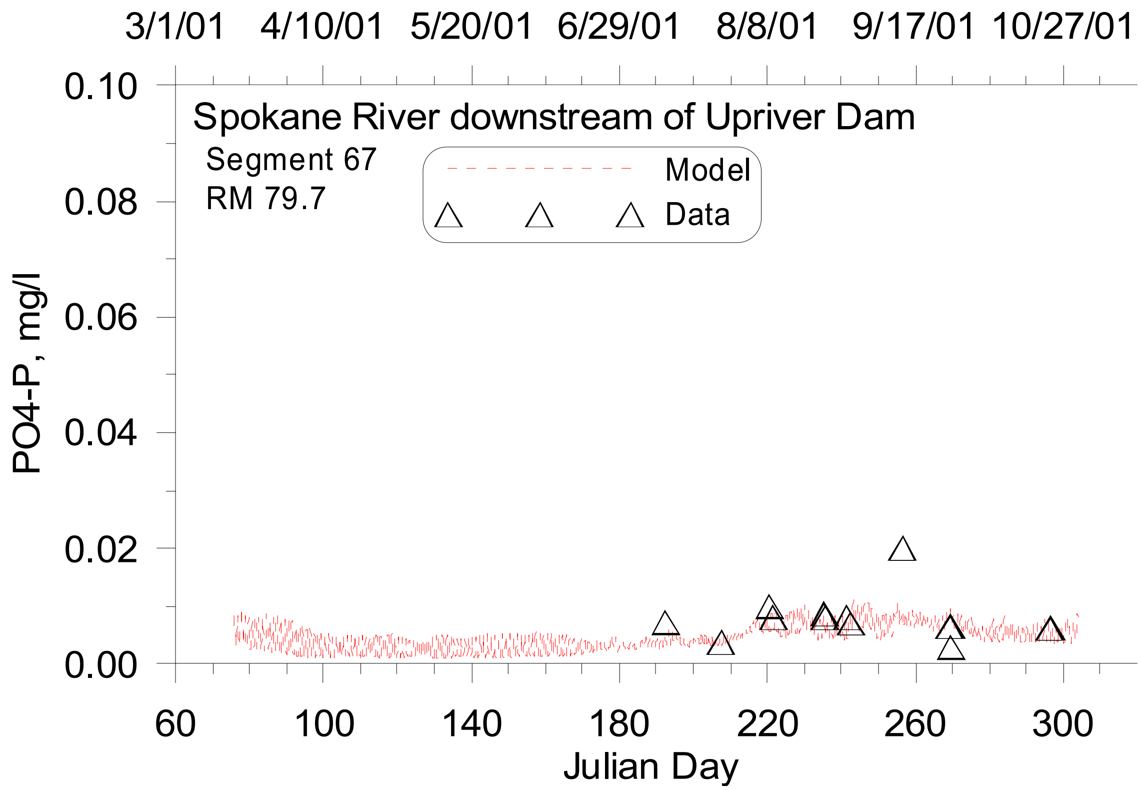

Figure 81. Comparison of model predicted soluble reactive phosphorus and data downstream of Upriver Dam

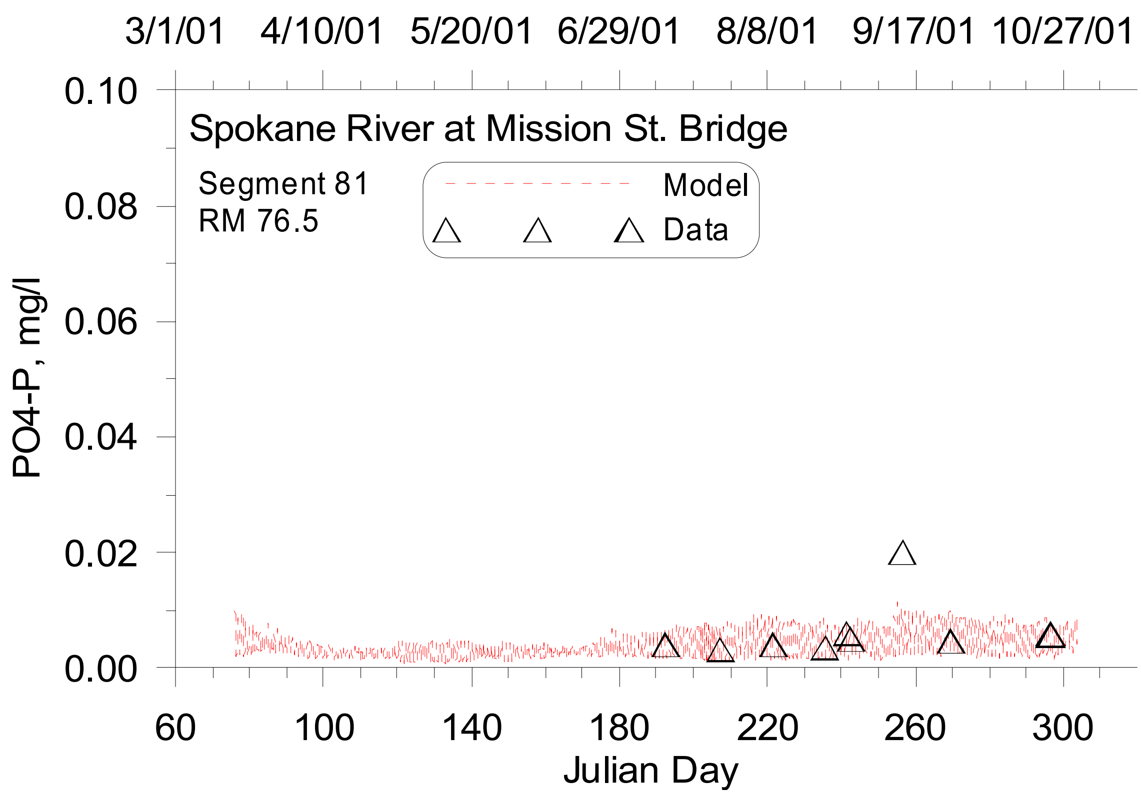

Figure 82. Comparison of model predicted soluble reactive phosphorus and data at Mission St. Bridge

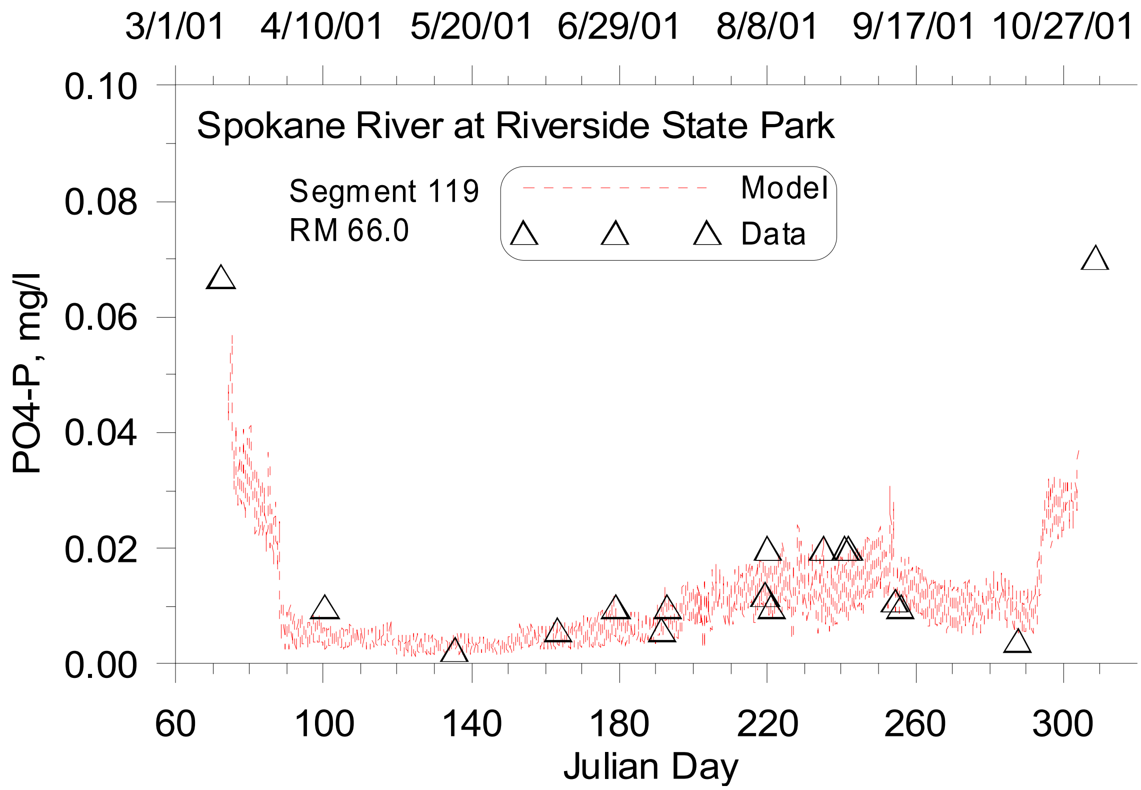

Figure 83. Comparison of model predicted soluble reactive phosphorus and data at Riverside State Park

Alkalinity

Alkalinity is a conservative constituent in CE-QUAL-W2 and was used with inorganic carbon to determine pH. Since it is conservative, it provided another check to the model's water balance and hydrodynamics. Figure 84 and Figure 85 show alkalinity vertical profile data and model results for sample site LL1 and LL3 in Long Lake. Table 30 shows AME and RMS error statistics for the Alkalinity concentration vertical profiles. Figure 86 through Figure 88 show alkalinity time series data compared with model results for three sites along the Spokane River. Table 31 lists alkalinity concentration model-data error statistics for five time series comparisons.

Table 30. Alkalinity profile error statistics, 2001

Site	n, # of data profile comparisons	Alkalinity model –data error statistics	
		AME, mg/L	RMS, mg/L
LL1	2	17.56	20.50
LL3	2	9.76	11.66

Table 31. Alkalinity time series error statistics, 2001

Site	n, # of data comparisons	Alkalinity model –data error statistics	
		AME, mg/L	RMS error, mg/L

SPK66.0	10	19.8	20.6
SPK76.5	11	20.1	20.8
SPK78.0	5	21.9	29.3
SPK79.7	13	28.0	30.7
SPK79.8	2	50.6	51.5
SPK84.7	5	52.4	53.3

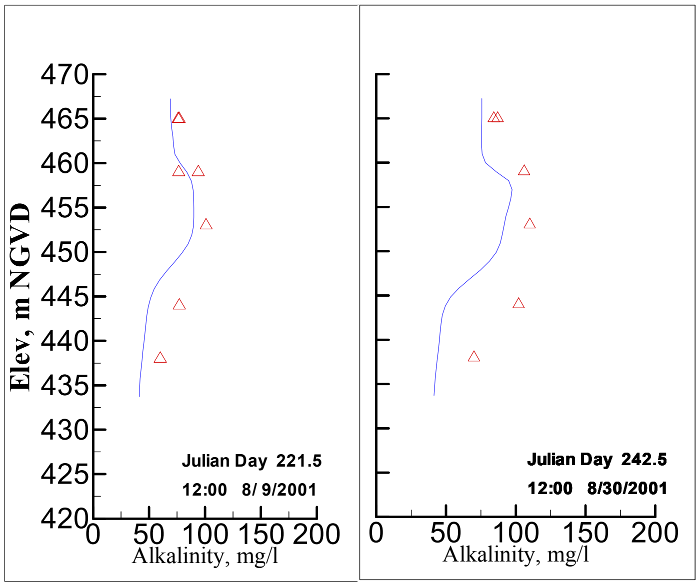

Figure 84. Comparison of model predicted vertical alkalinity profiles and data for Long Lake at Station 1 (Segment 180).

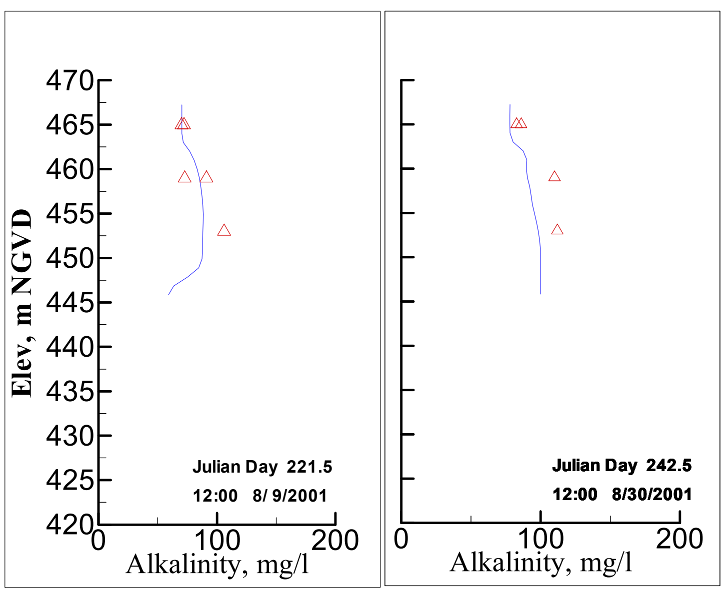

Figure 85. Comparison of model predicted vertical alkalinity profiles and data for Long Lake at Station 3 (Segment 168).

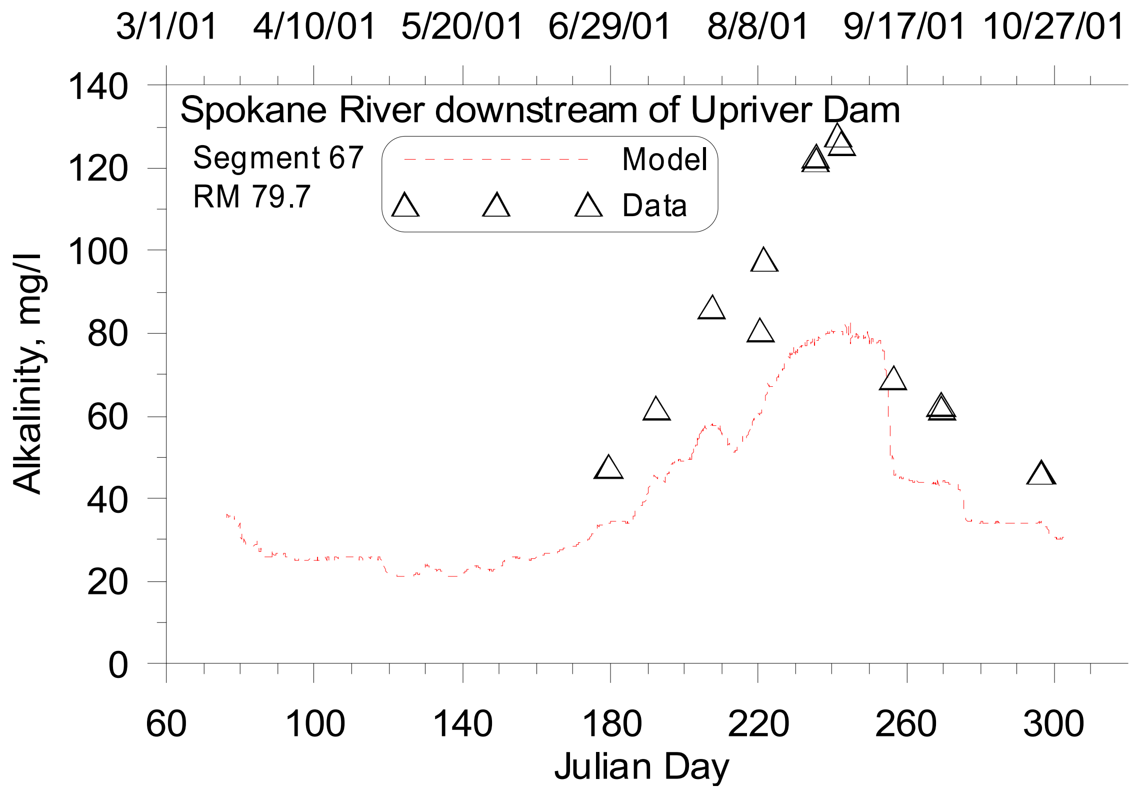

Figure 86. Comparison of model predicted alkalinity and data downstream of Upriver Dam

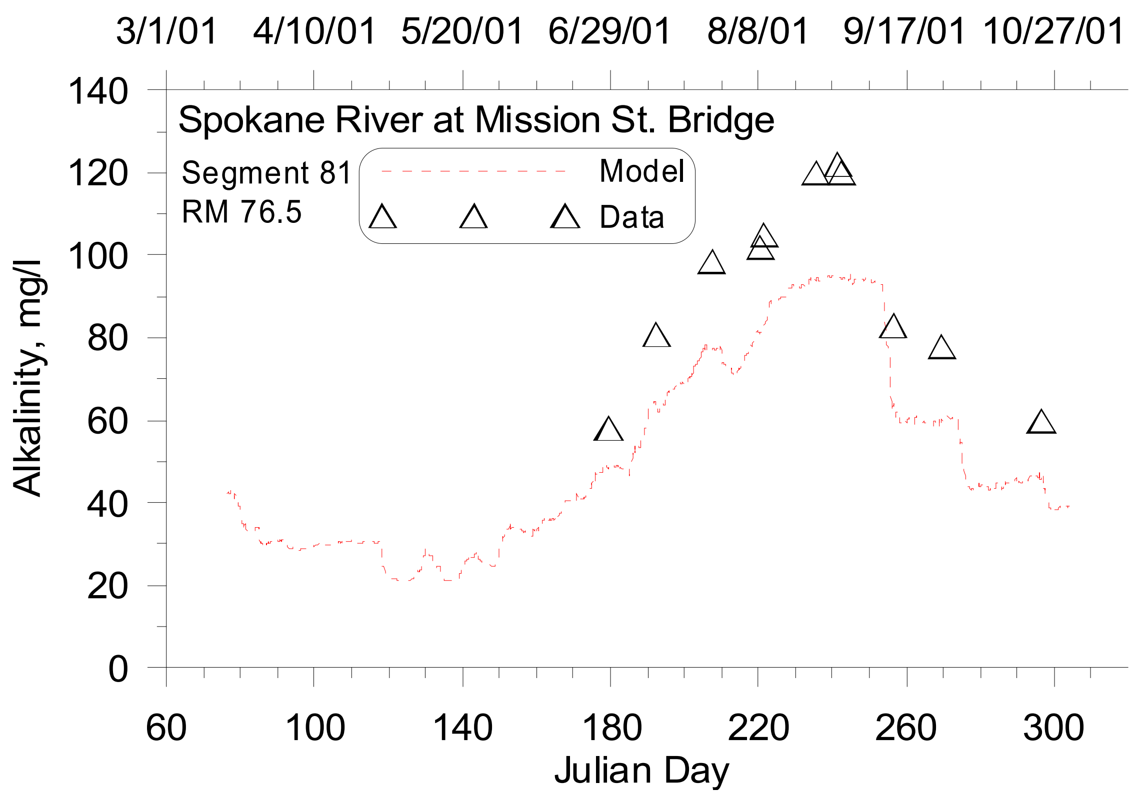

Figure 87. Comparison of model predicted alkalinity and data at Mission St. Bridge

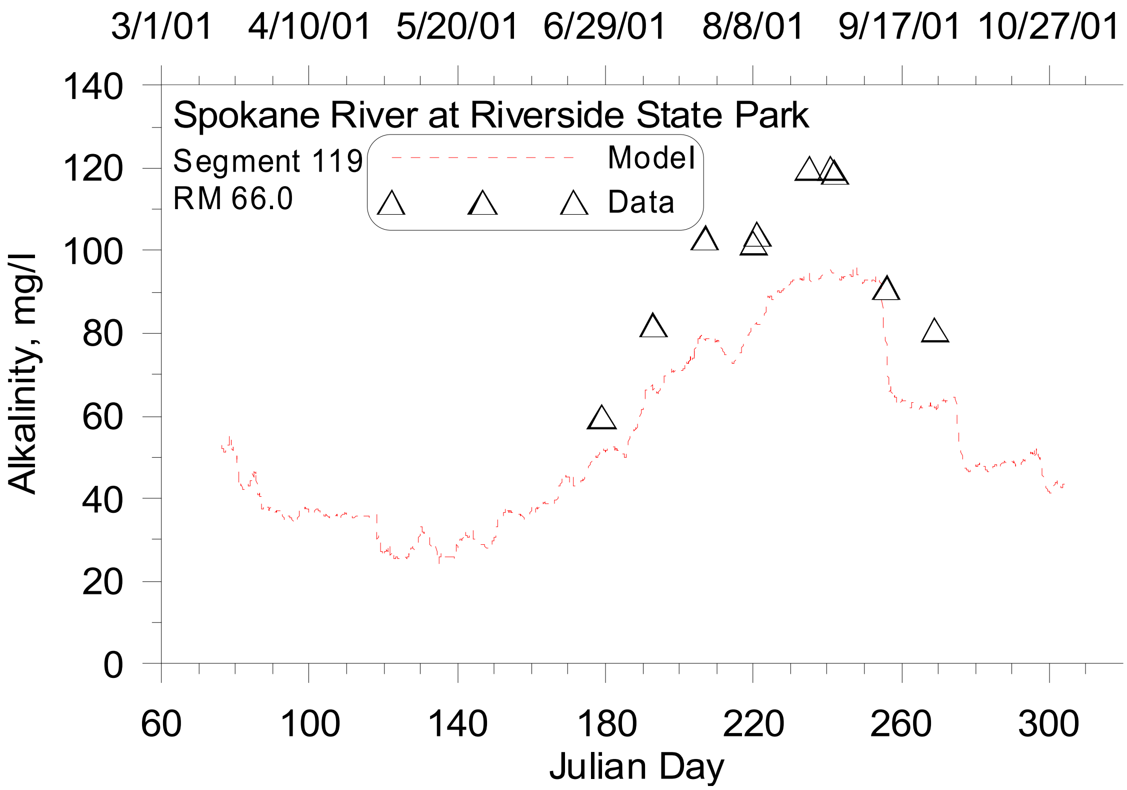

Figure 88. Comparison of model predicted alkalinity and data at Riverside State Park

Chlorophyll a

Model predicted algal biomass was compared to chlorophyll a data by assuming an algal biomass to chlorophyll a ratio of 130. Phytoplankton maximum growth rate was calibrated to1.5 d^{-1}. Of special importance was the calibration of maximum light saturation coefficient to 40 W/m^2, which permitted more accurate predictions of phytoplankton growth over depth.

Chlorophyll a vertical profiles were collected in Long Lake in 2001 at three sites. Figure 89 to Figure 91 show Chlorophyll a profile data and model results for the three sites. Table 32 shows AME and RMS error statistics for the chlorophyll a vertical profiles. Figure 92 through Figure 95 show chlorophyll a time series data compared with model results for four locations along the Spokane River. Table 33 lists chlorophyll a model-data error statistics for five time series comparisons.

Table 32. Chlorophyll a profile error statistics, 2001

Site	n, # of data profile comparisons	Chlorophyll a model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL1	2	0.005	0.006
LL3	2	0.005	0.005
LL4	1	0.017	0.017

Table 33. Chlorophyll a time series error statistics, 2001

Site	n, # of data comparisons	Chlorophyll a model –data error statistics	
		AME, mg/L	RMS error, mg/L
SPK66.0	4	0.002	0.002
SPK76.5	5	0.001	0.002
SPK79.7	5	0.002	0.002
SPK79.8	3	0.005	0.007
SPK84.7	2	0.000	0.000

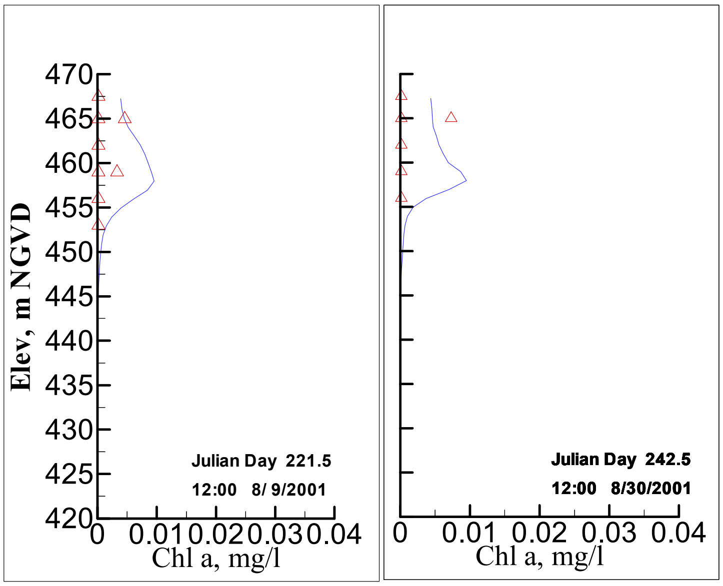

Figure 89. Comparison of model predicted vertical chlorophyll a profiles and data for Long Lake at Station 1 (Segment 180).

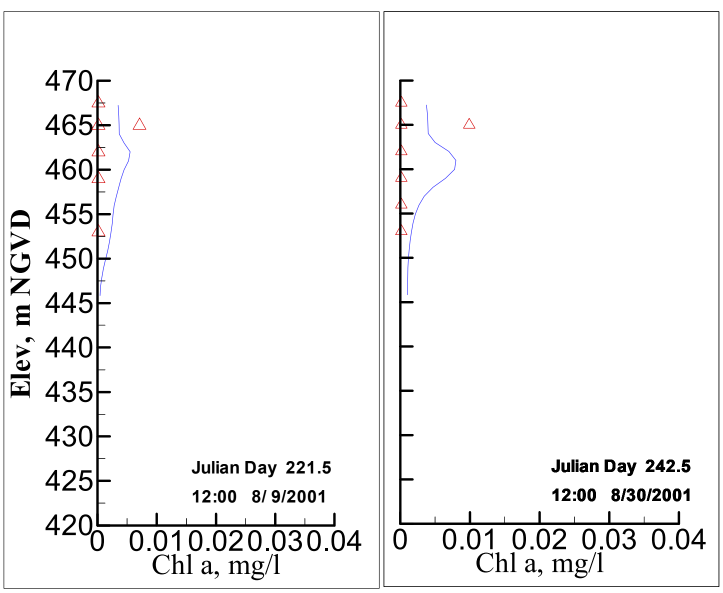

Figure 90. Comparison of model predicted vertical chlorophyll a profiles and data for Long Lake at Station 3 (Segment 168).

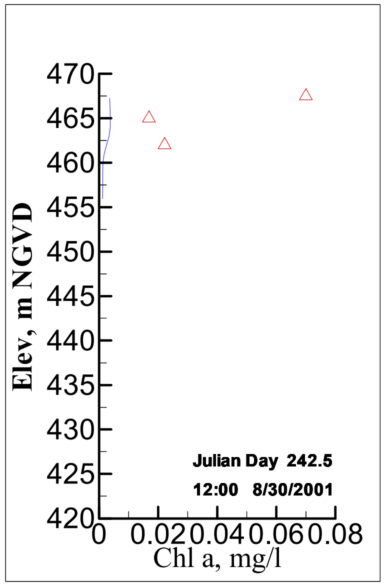

Figure 91. Comparison of model predicted vertical chlorophyll a profiles and data for Long Lake at Station 4 (Segment 161).

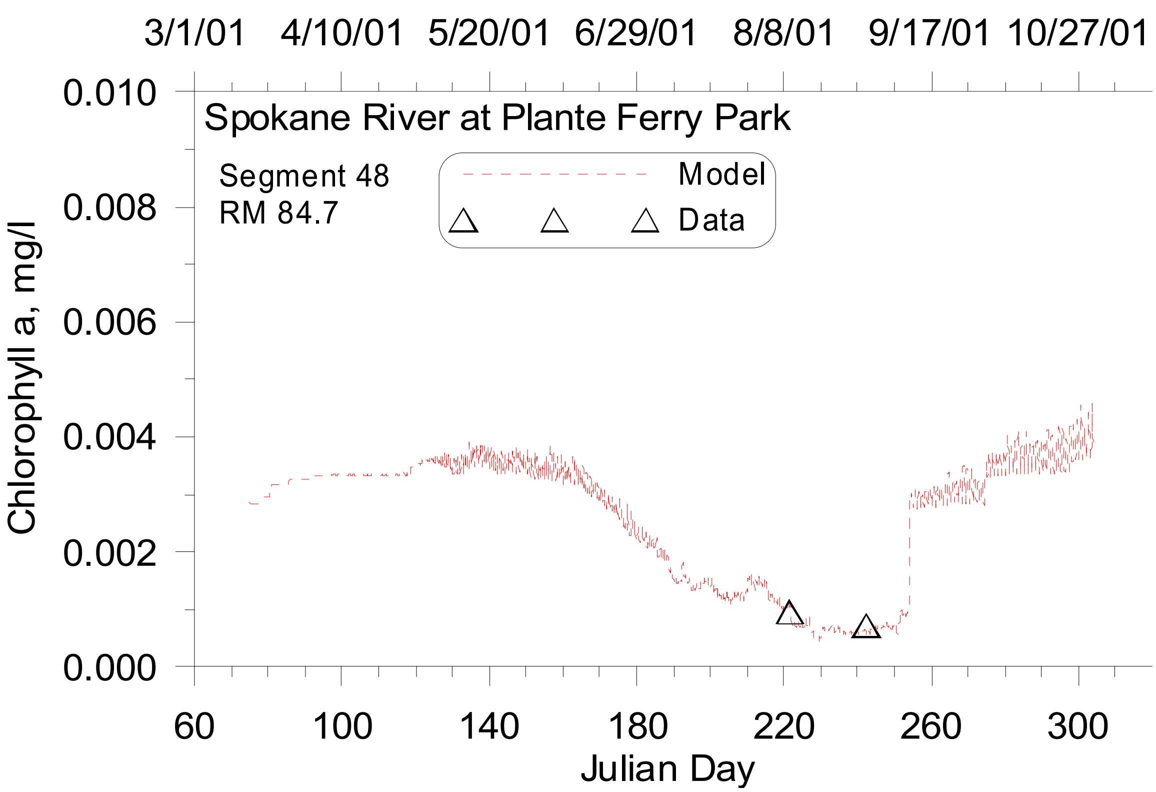

Figure 92. Comparison of model predicted chlorophyll a and data at Plante Ferry Park

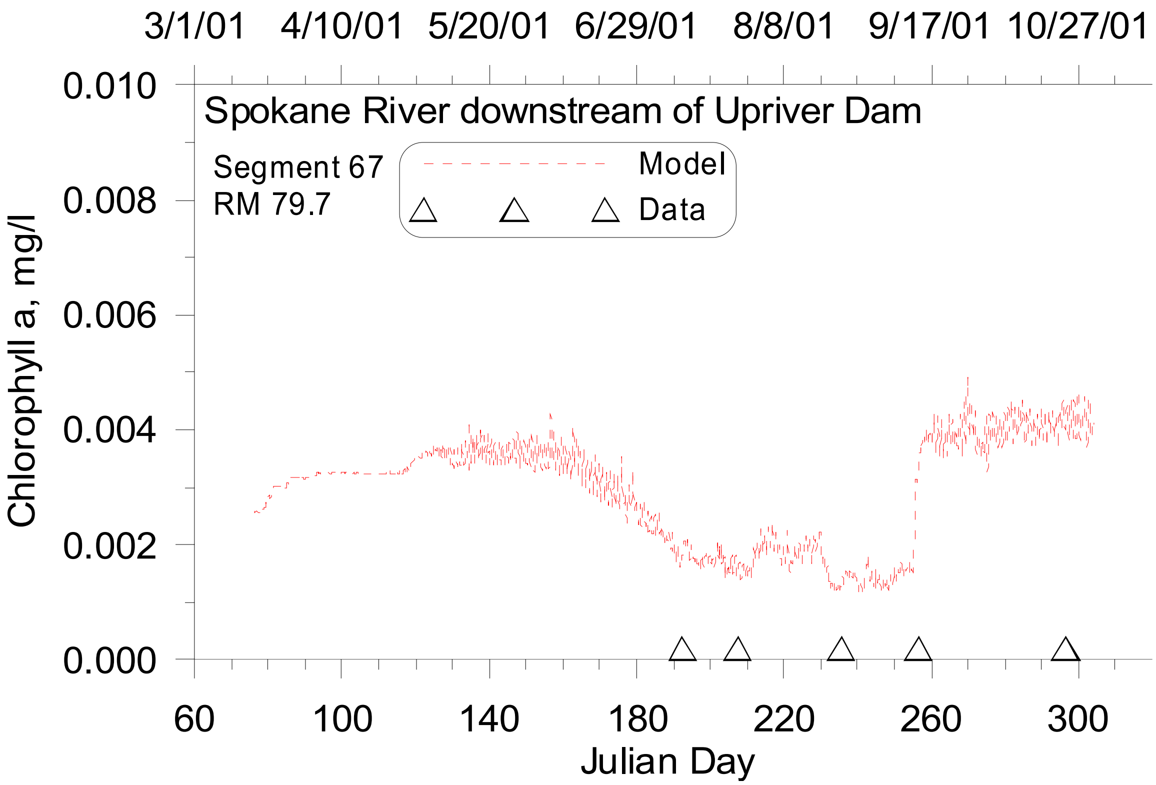

Figure 93. Comparison of model predicted chlorophyll a and data downstream of Upriver Dam

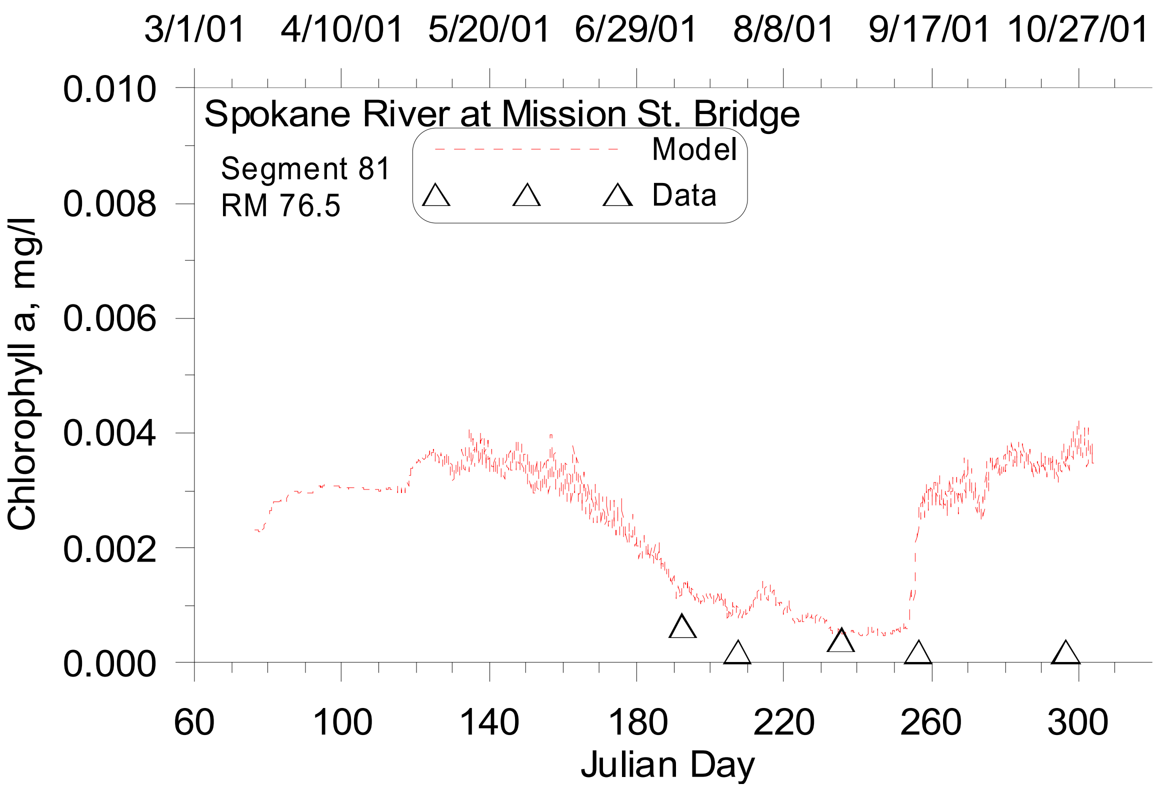

Figure 94. Comparison of model predicted chlorophyll a and data at Mission St. Bridge

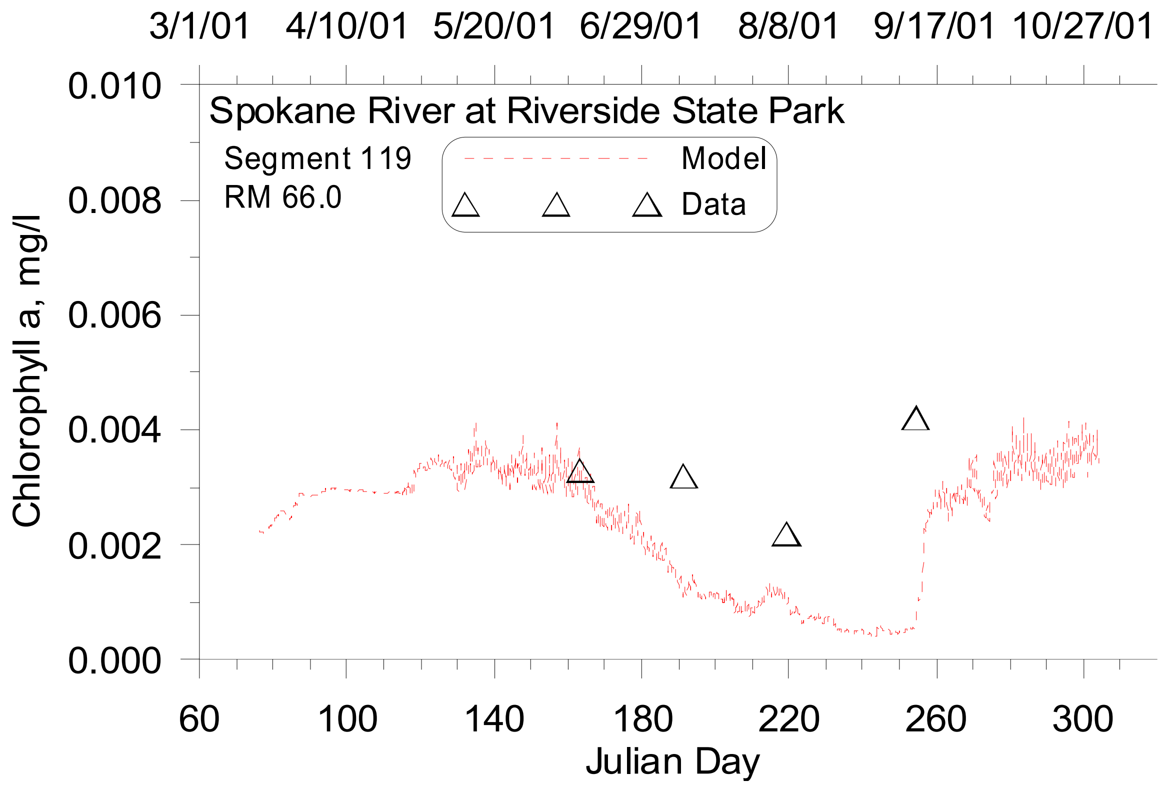

Figure 95. Comparison of model predicted chlorophyll a and data at Riverside State Park

Total Organic Carbon

Model predicted total organic carbon concentrations were compared with data providing a means to determine if correct amounts organic matter were being simulated. In CE-QUAL-W2 total organic carbon is a derived variable and is total of all CBOD, phytoplankton, and organic matter compartments.

Total organic carbon vertical profiles were collected at two sites in Long Lake in 2001. Figure 96 and Figure 97 show total organic carbon profile data and model results for the sites LL1 and LL3. Table 34 shows AME and RMS error statistics for the total organic carbon vertical profiles. Figure 98 to Figure 100 show total organic carbon time series data compared with model results for three sites along the Spokane River.
Table 35 includes total organic carbon model-data error statistics for five time series comparisons.

Table 34. Total organic carbon profile error statistics, 2001

Site	n, # of data profile comparisons	Total organic carbon model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL1	2	0.64	0.76
LL3	2	0.62	0.65

Table 35. Total organic carbon time series error statistics, 2001

Site	n, # of data comparisons	Total Organic C model – data error statistics	
		AME, mg/L	RMS error, mg/L
SPK66.0	18	0.96	1.09
SPK76.5	10	0.74	1.00
SPK78.0	2	2.52	2.59
SPK79.7	14	0.65	0.69
SPK79.8	2	0.45	0.46
SPK84.7	5	0.35	0.43

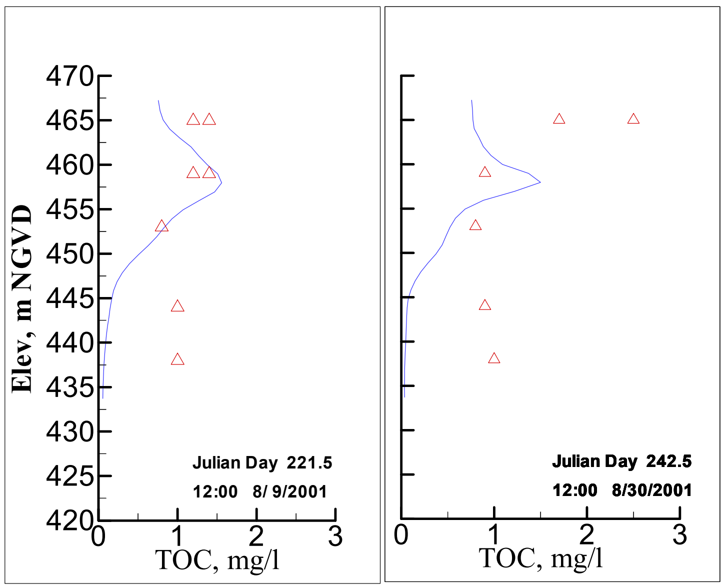

Figure 96. Comparison of model predicted total organic carbon vertical profiles and data for Long Lake at Station 1 (Segment 180).

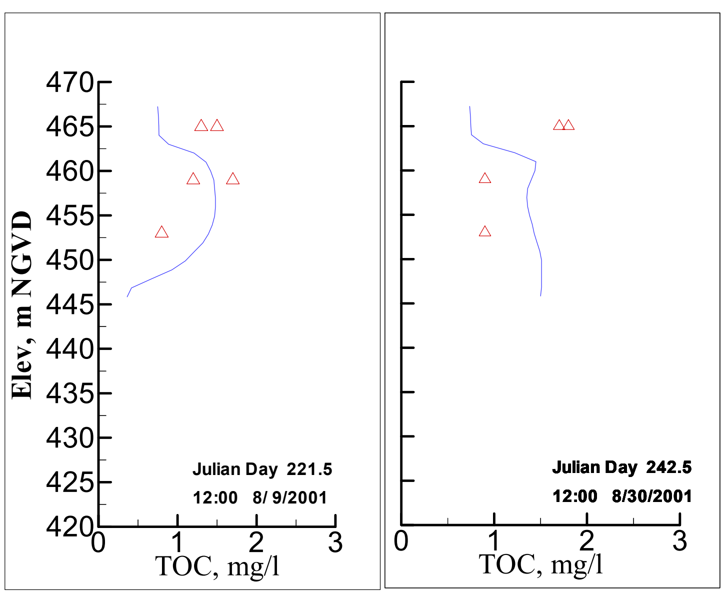

Figure 97. Comparison of model predicted total organic carbon vertical profiles and data for Long Lake at Station 3 (Segment 168).

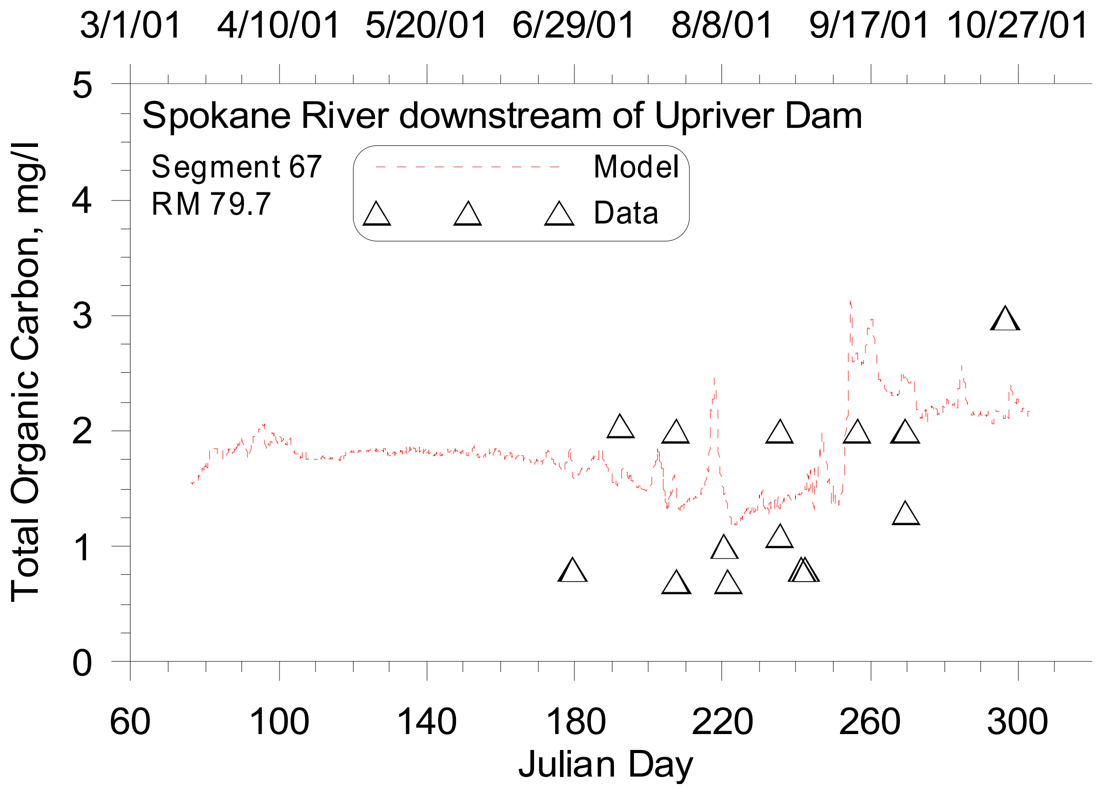

Figure 98. Comparison of model predicted total organic carbon and data downstream of Upriver Dam

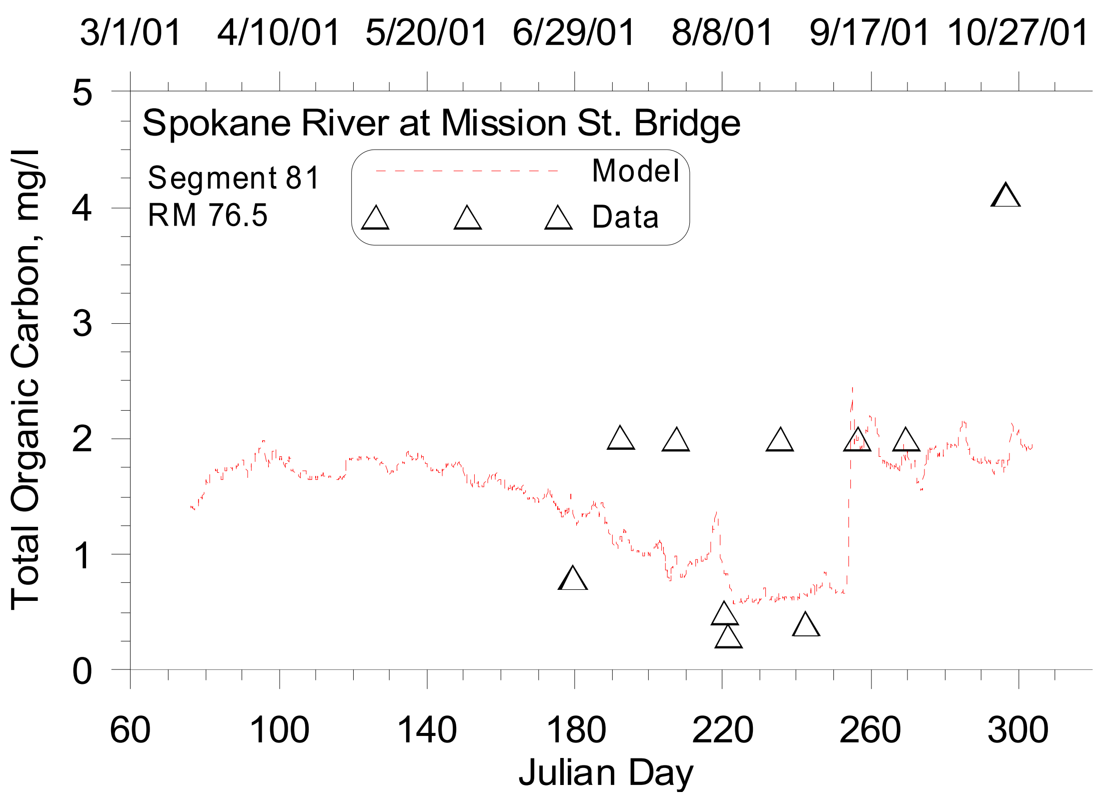

Figure 99. Comparison of model predicted total organic carbon and data at Mission St. Bridge

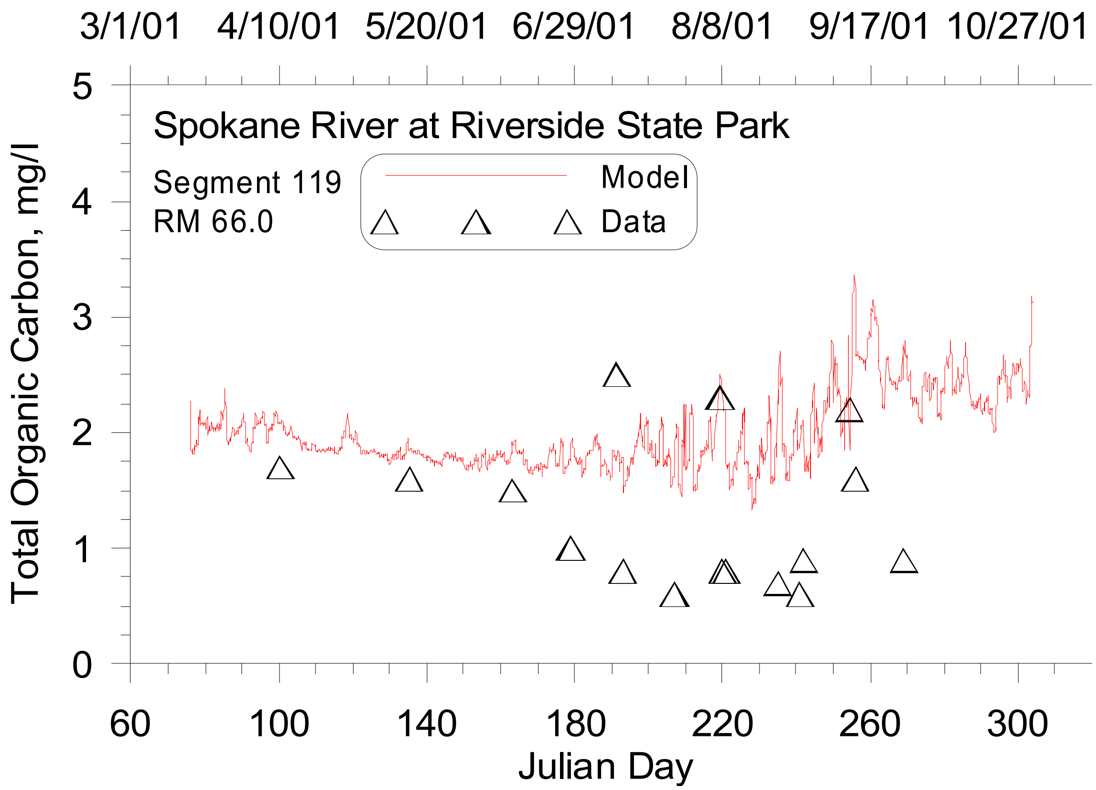

Figure 100. Comparison of model predicted total organic carbon and data at Riverside State Park

Total Nitrogen

Total nitrogen is a derived variable in CE-QUAL-W2 and is the sum of all nitrogen contained in ammonia nitrogen, nitrite-nitrate nitrogen, the CBOD compartments, phytoplankton, and organic matter compartments.

Total nitrogen vertical profiles were collected in Long Lake in 2001. Figure 101 and Figure 102 show total nitrogen vertical profile data and model results for two locations from RM 32.7 to 54.5. Table 36 shows AME and RMS error statistics for the total nitrogen vertical profiles. Figure 103 to Figure 105 show total nitrogen time series data compared with model results for three sites along the Spokane River. Table 37 shows the model-data error statistics for the time series comparisons.

Table 36. Total nitrogen profile error statistics, 2001

Site	n, # of data profile comparisons	Total nitrogen model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL1	2	0.65	0.66
LL3	2	0.88	0.89

Table 37. Total nitrogen time series error statistics, 2001

Site	n, # of data comparisons	Total N model –data error statistics	
		AME, mg/L	RMS error, mg/L
SPK66.0	12	0.32	0.40
SPK79.8	2	0.11	0.11
SPK84.7	2	0.10	0.11

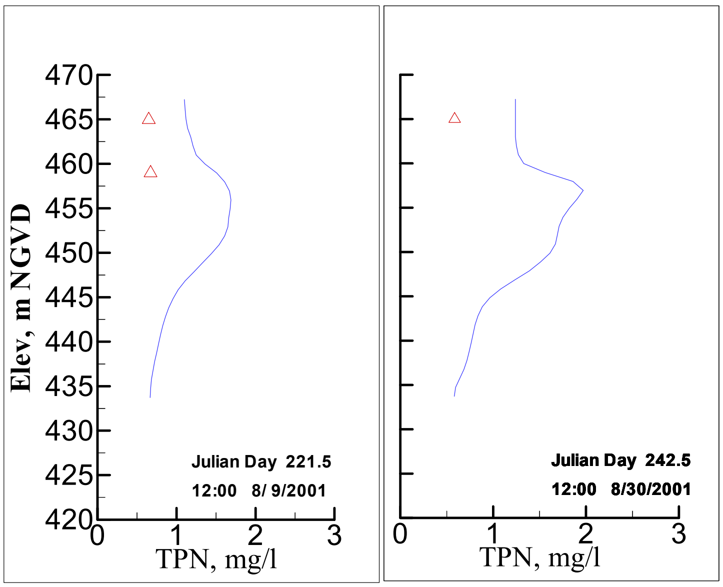

Figure 101. Comparison of model predicted total nitrogen vertical profiles and data for Long Lake at Station 1 (Segment 180).

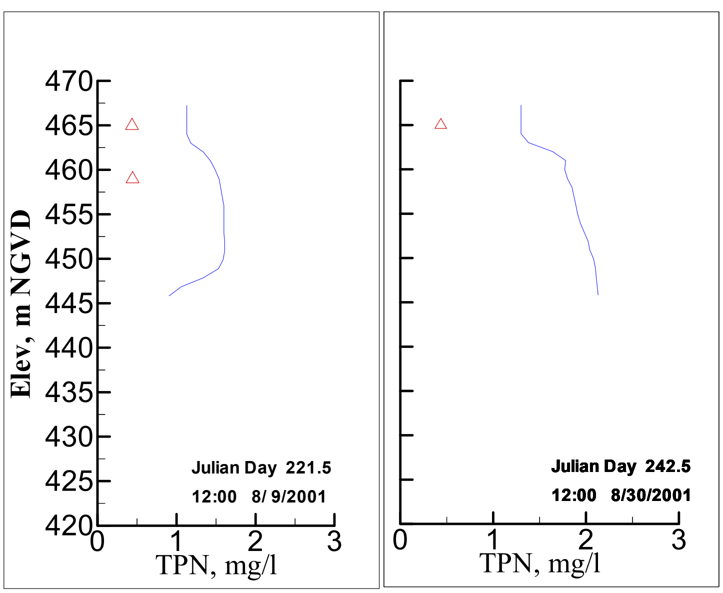

Figure 102. Comparison of model predicted total nitrogen vertical profiles and data for Long Lake at Station 3 (Segment 168).

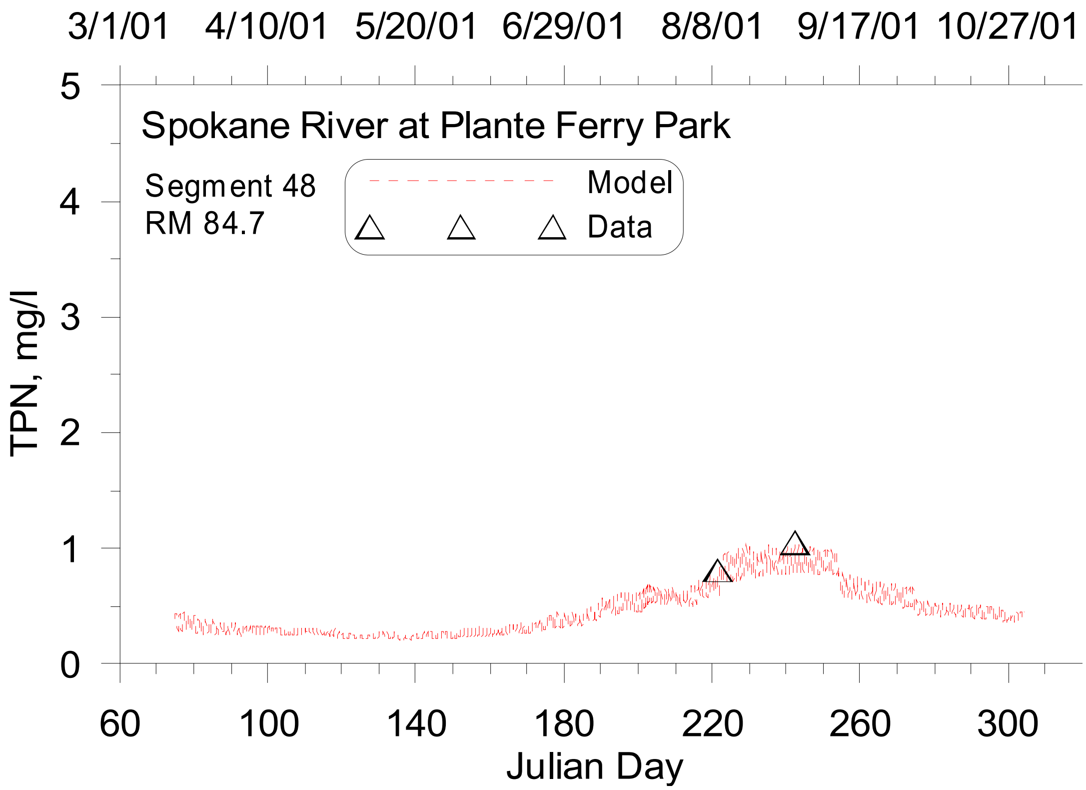

Figure 103. Comparison of model predicted total nitrogen and data at Plante Ferry Park

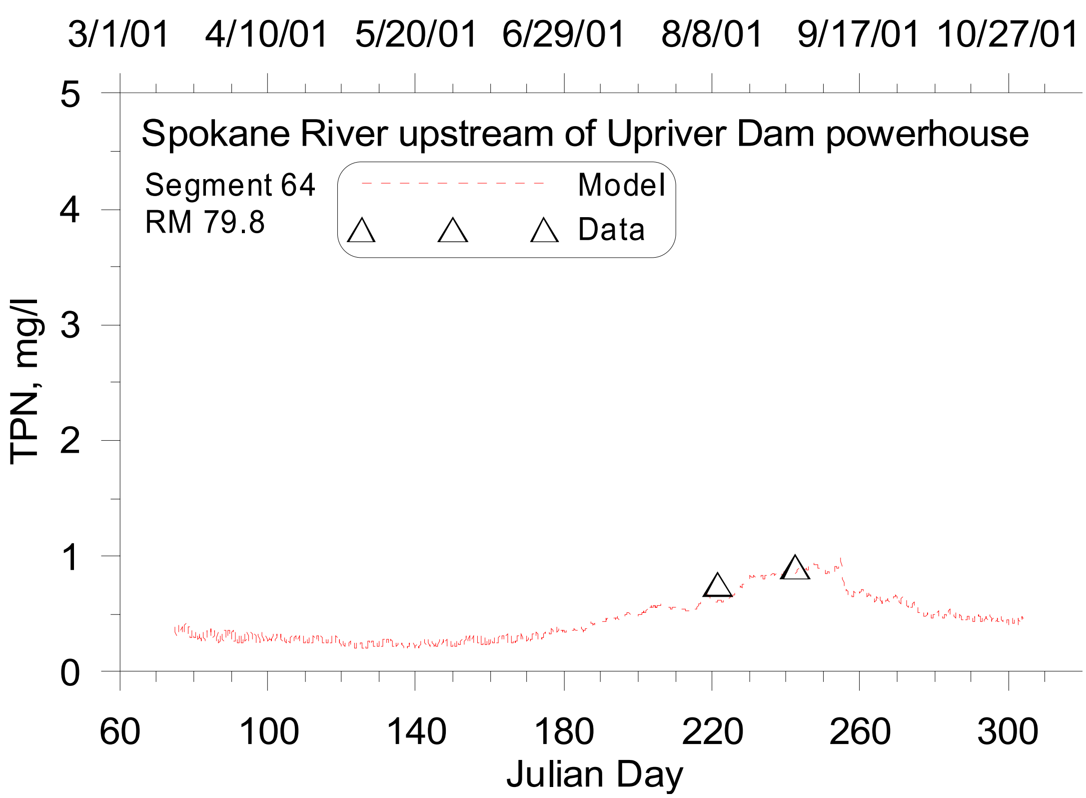

Figure 104. Comparison of model predicted total nitrogen and data upstream of Upriver Dam powerhouse

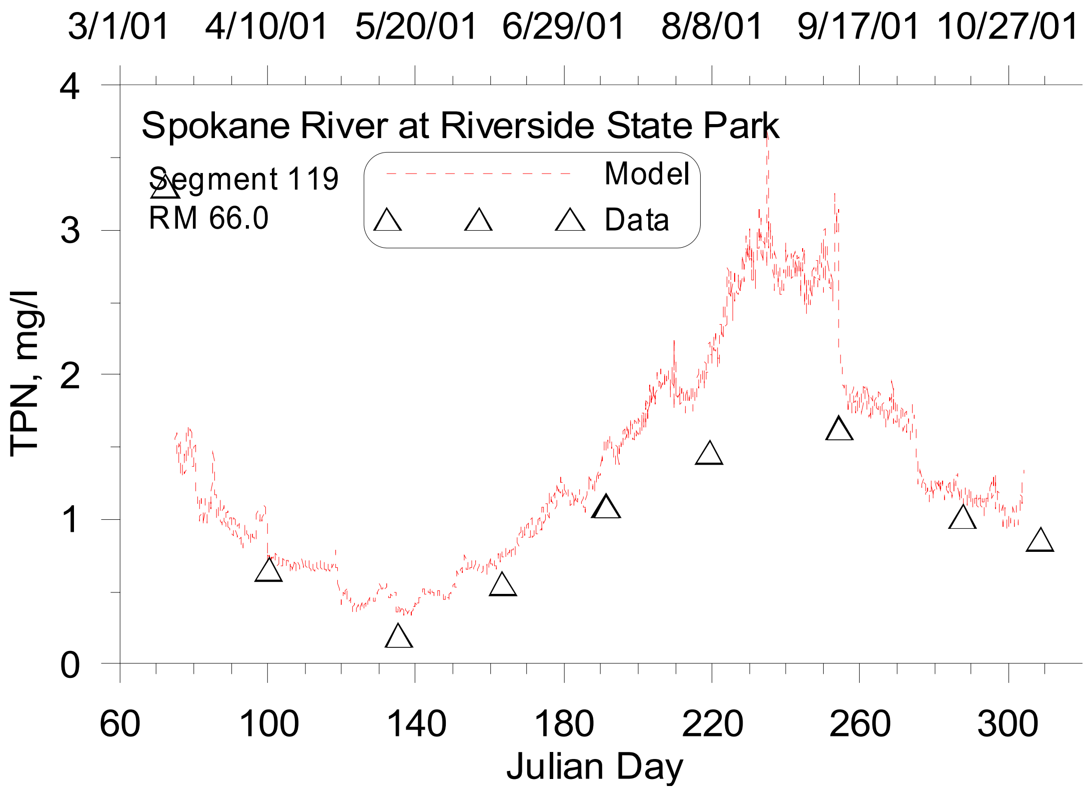

Figure 105. Comparison of model predicted total nitrogen and data at Riverside State Park

Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen (TKN) is a derived variable in CE-QUAL-W2 and is the sum of all organic and ammonia nitrogen. TKN vertical profiles were collected in Long Lake in 2001 at 2 sites. Figure 106 and Figure 107 show TKN vertical profile data and model results for two locations from RM 32.7 to 54.5. Table 38 shows AME and RMS error statistics for the TKN vertical profiles. Figure 108 to Figure 111 show TKN time series data compared with model results for four sites along the Spokane River. Table 39 shows the model-data error statistics for the time series comparisons.

Table 38. Total Kjeldahl Nitrogen profile error statistics, 2001

Site	n, # of data profile comparisons	TKN model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL1	2	0.42	0.56
LL3	2	0.28	0.38

Table 39. Total Kjeldahl Nitrogen time series error statistics, 2001

Site	n, # of data comparisons	TKN model –data error statistics	
		AME, mg/L	RMS error, mg/L

SPK66.0	10	0.20	0.23
SPK76.5	10	0.87	1.40
SPK79.7	14	0.40	0.51
SPK84.7	4	0.22	0.28

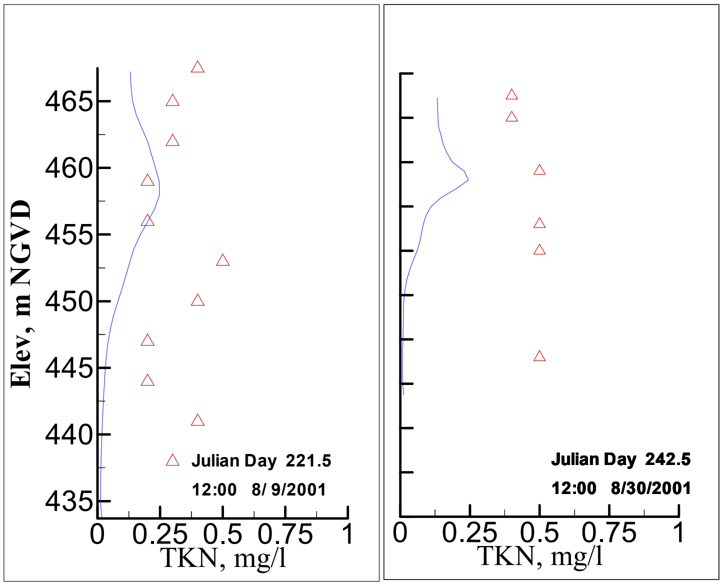

Figure 106. Comparison of model predicted vertical total Kjeldahl profiles and data for Long Lake at Station 1 (Segment 180).

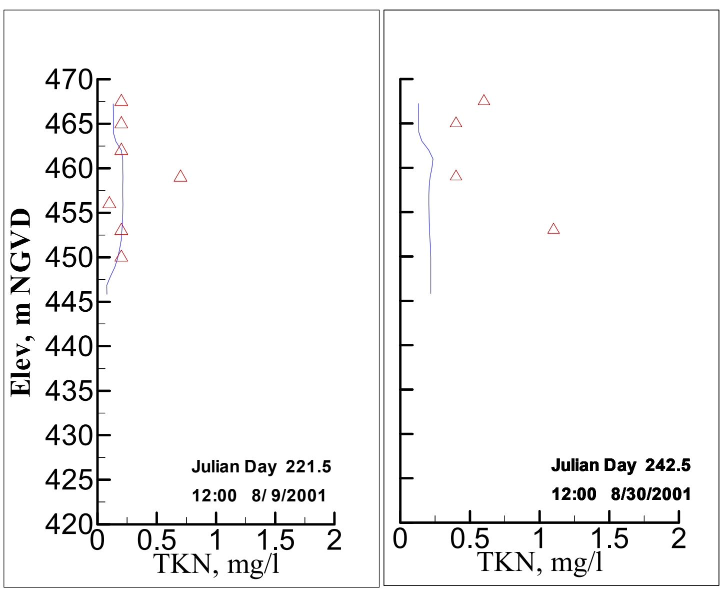

Figure 107. Comparison of model predicted vertical total Kjeldahl profiles and data for Long Lake at Station 3 (Segment 168).

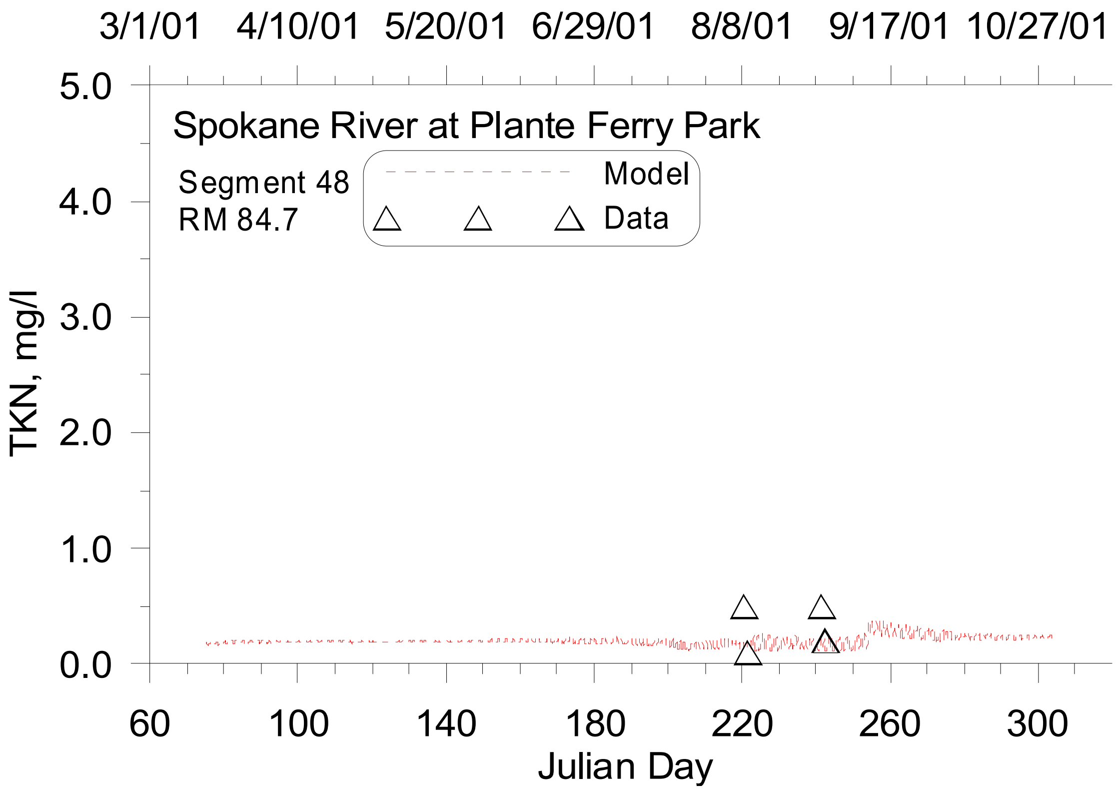

Figure 108. Comparison of model predicted total Kjeldahl nitrogen and data at Plante Ferry Park

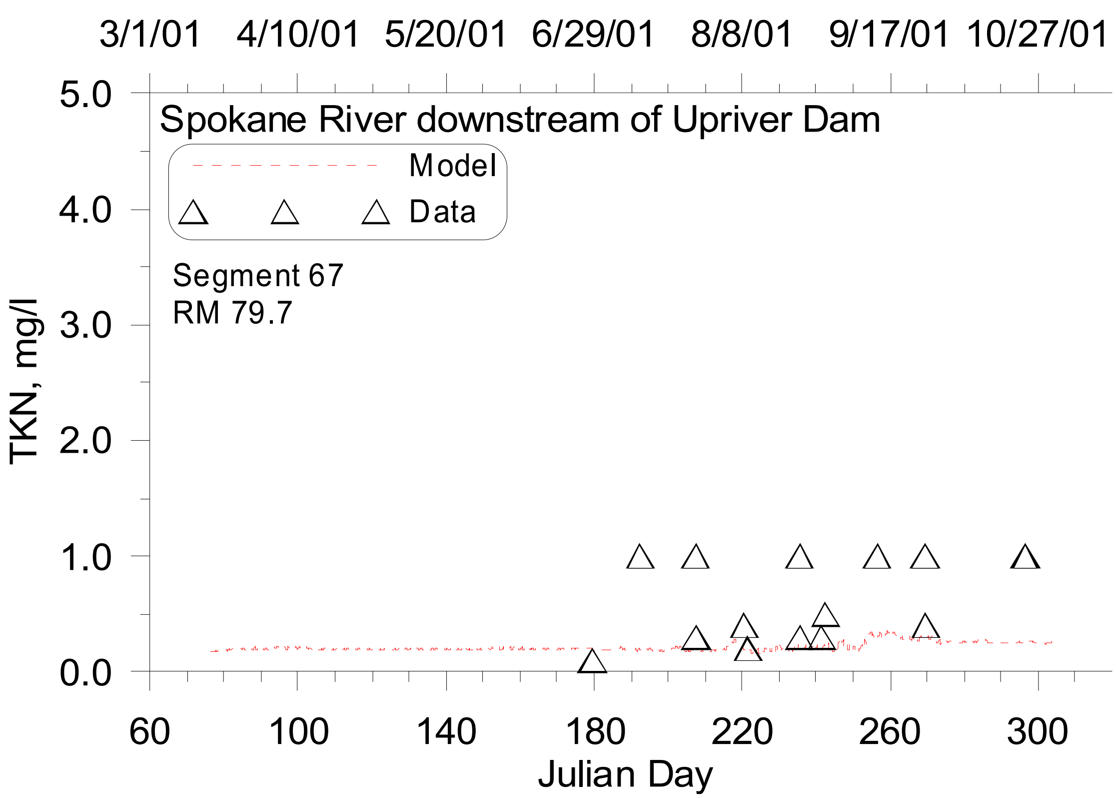

Figure 109. Comparison of model predicted total Kjeldahl nitrogen and data downstream of Upriver Dam

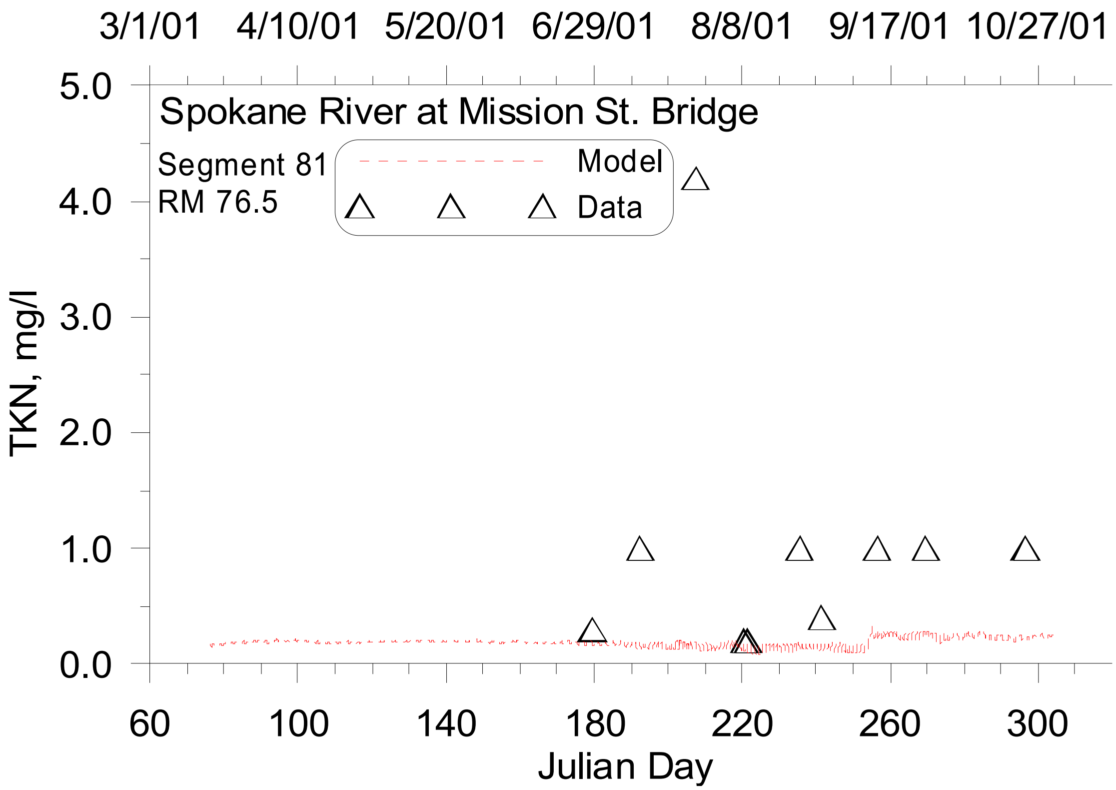

Figure 110. Comparison of model predicted total Kjeldahl nitrogen and data at Morrison St. Bridge

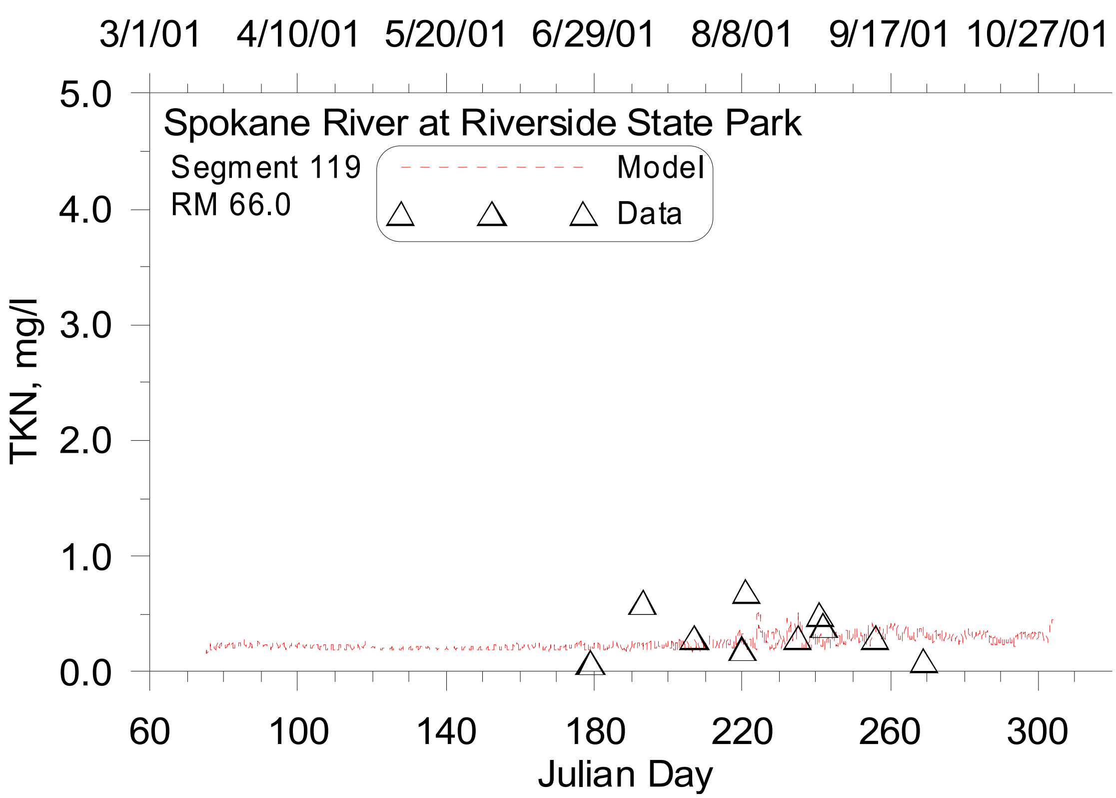

Figure 111. Comparison of model predicted total Kjeldahl nitrogen and data at Riverside State Park

Total Phosphorus

Total Phosphorus (TP) is a derived variable in CE-QUAL-W2 and is the sum of all phosphorus model compartments. TP vertical profiles were collected in Long Lake in 2001 at 2 sites. Figure 113 and Figure 115 show TP vertical profile data and model results for two locations from RM 32.7 to 54.5. Table 40 shows AME and RMS error statistics for the TP vertical profiles. Figure 114 to Figure 117 show TP time series data compared with model results for four sites along the Spokane River. Table 41 shows the model-data error statistics for the time series comparisons.

Table 40. Total Phosphorus profile error statistics, 2001

Site	n, # of data profile comparisons	TP model –data error statistics	
		AME, mg/L	RMS error, mg/L
LL1	2	0.010	0.013
LL3	2	0.009	0.010

Table 41. Total Phosphorus time series error statistics, 2001

Site	n, # of data comparisons	TP model –data error statistics	
		AME, mg/L	RMS error, mg/L
SPK66.0	10	0.004	0.005
SPK76.5	10	0.008	0.011
SPK79.7	14	0.007	0.008
SPK79.8	2	0.012	0.014
SPK84.7	4	0.007	0.007

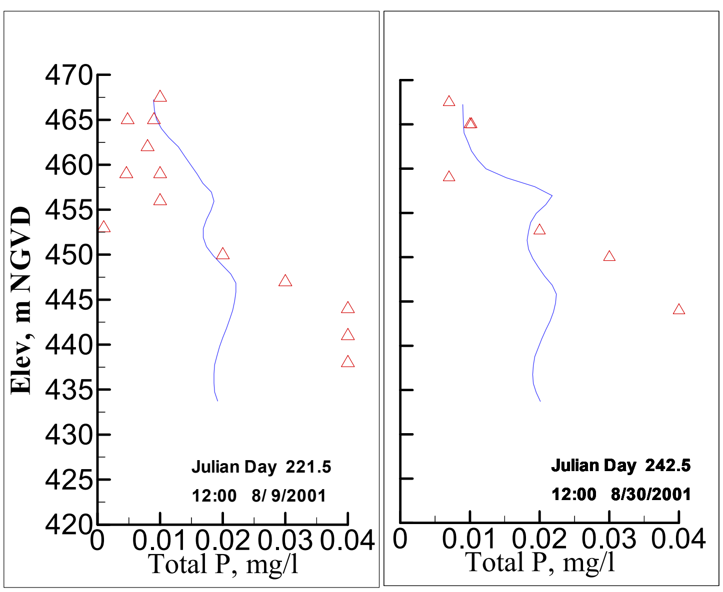

Figure 112. Comparison of model predicted vertical Total Phosphorus profiles and data for Long Lake at Station 1 (Segment 180).

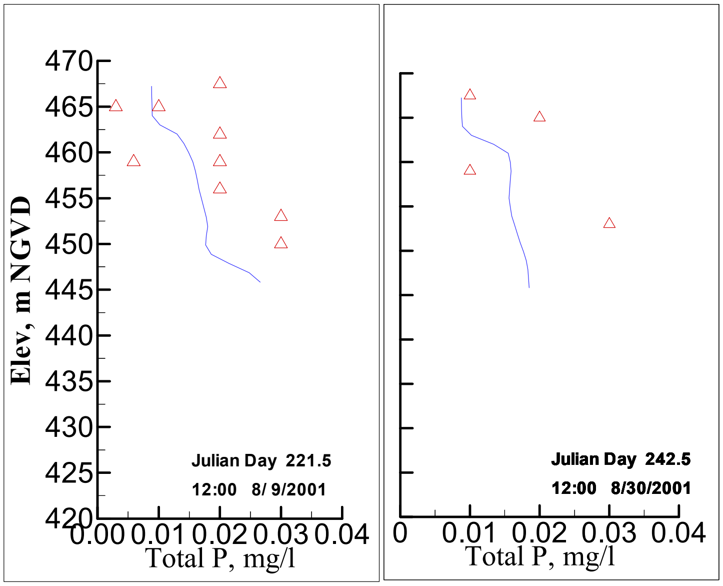

Figure 113. Comparison of model predicted vertical Total Phosphorus profiles and data for Long Lake at Station 3 (Segment 168).

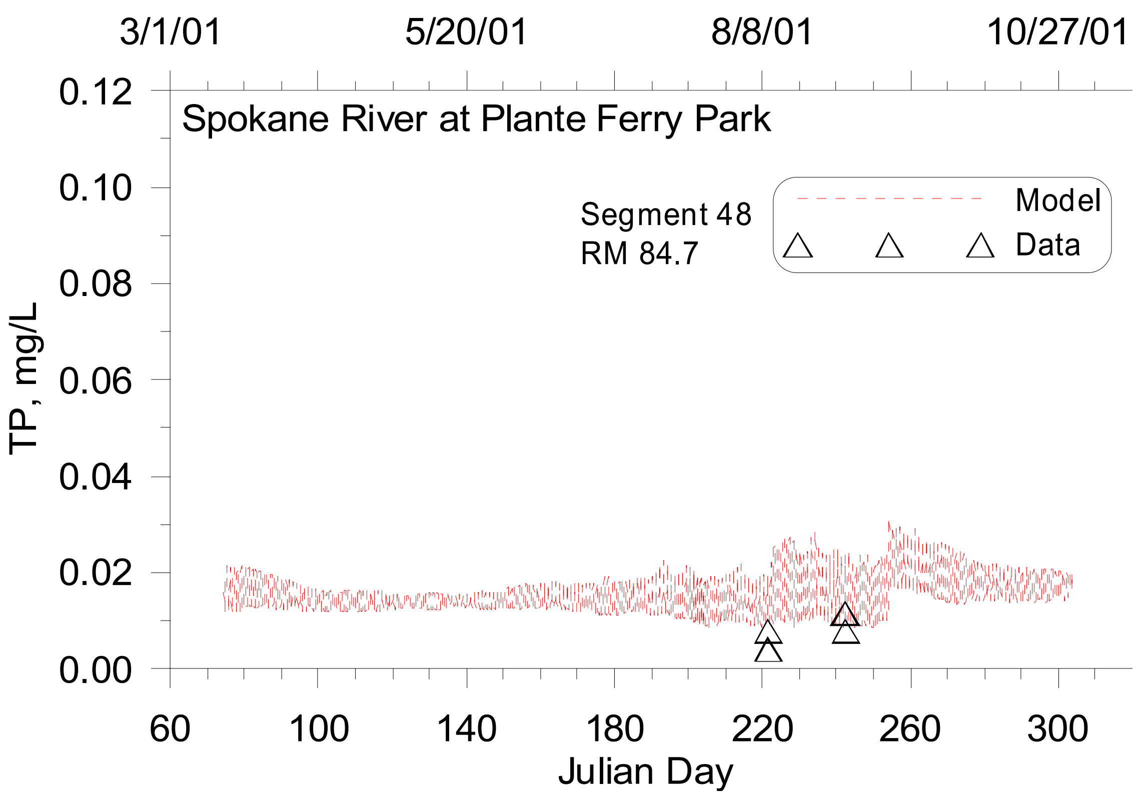

Figure 114. Comparison of model predicted Total Phosphorus and data at Plante Ferry Park

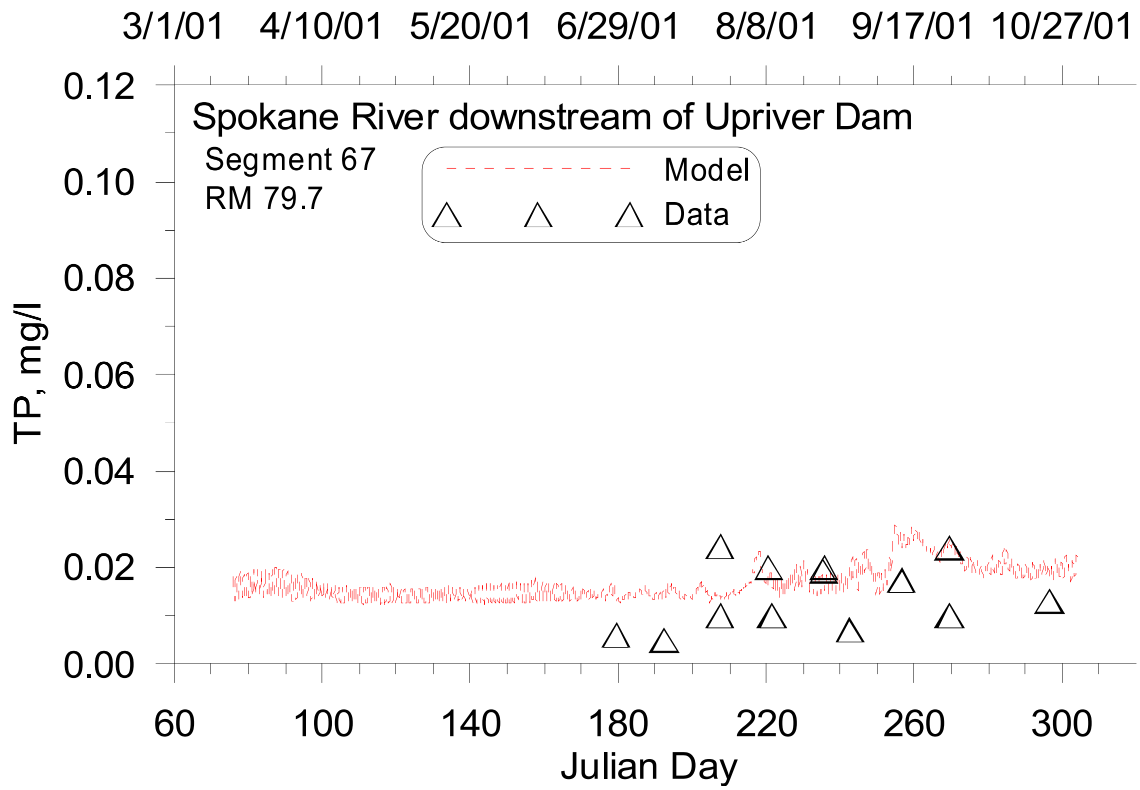

Figure 115. Comparison of model predicted Total Phosphorus and data downstream of Upriver Dam

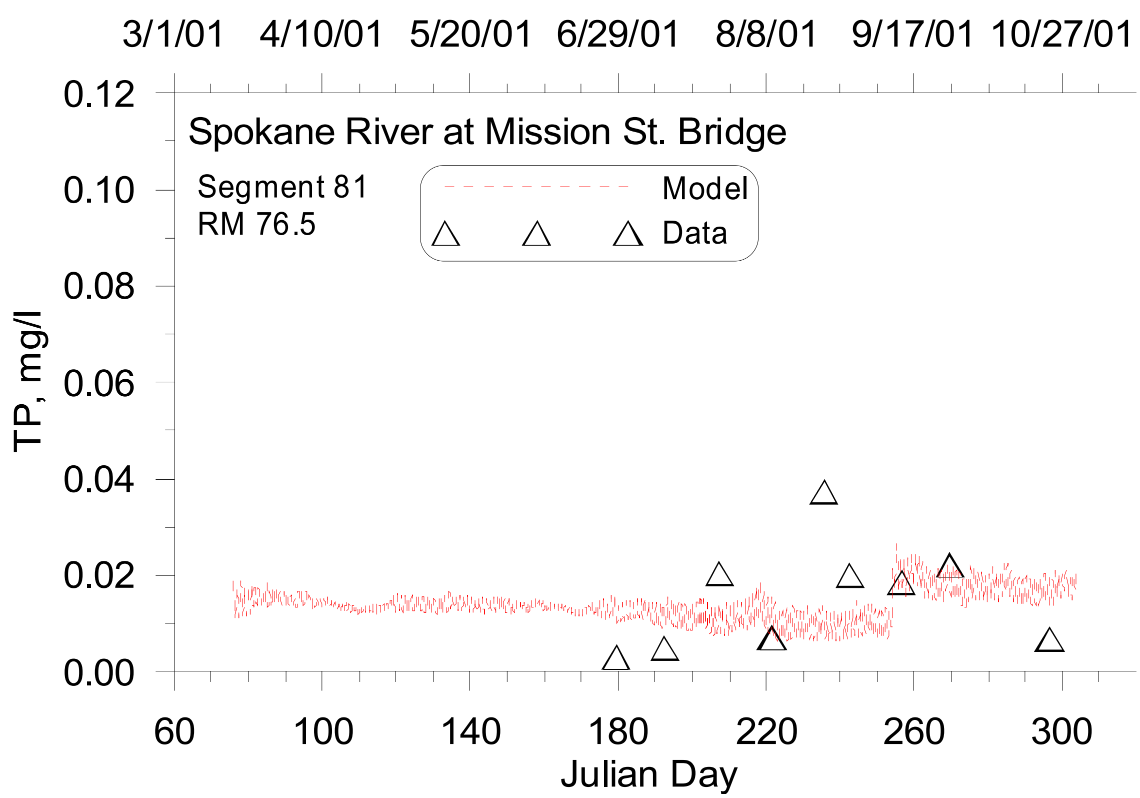

Figure 116. Comparison of model predicted Total Phosphorus and data at Mission St. Bridge

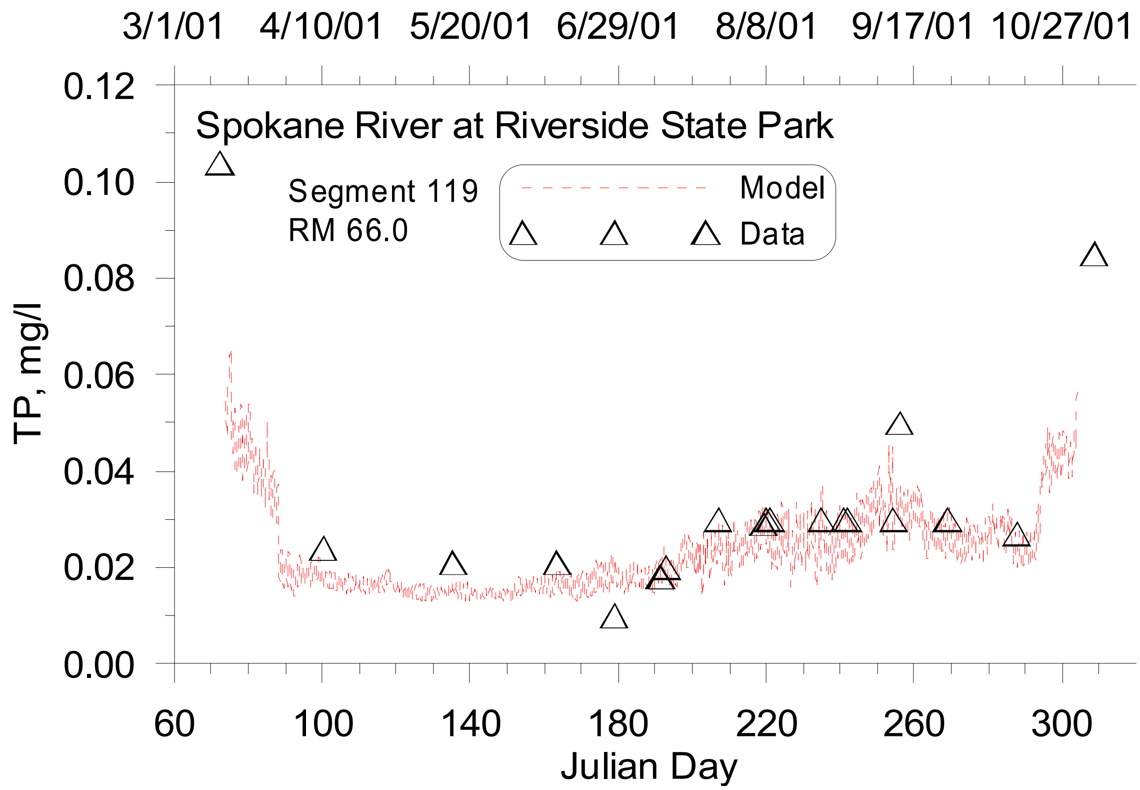

Figure 117. Comparison of model predicted Total Phosphorus and data at Riverside State Park

Ultimate Carbonaceous Biochemical Oxygen Demand

Ultimate carbonaceous biochemical oxygen demand (CBODu) data were available at only two locations in the Spokane River to compare with model results. There were no COBDu vertical profiles taken in the model domain. Figure 118 compares the model predicted CBOD ultimate and data for the Spokane River site at Riverside State Park (RM 66.0). Figure 119 compares the model predicted CBOD ultimate and data for the Spokane River site at the bridge just below the Nine Mile Dam.

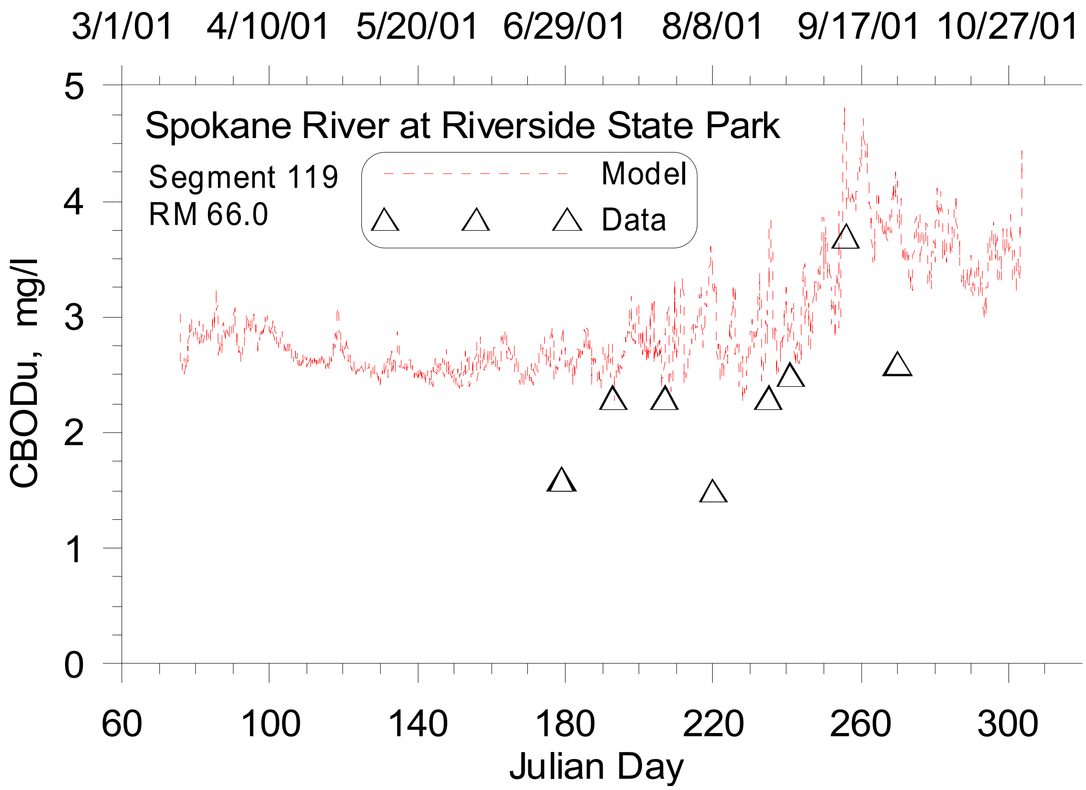

Figure 118. Comparison of model predicted CBOD ultimate and data at Riverside State Park

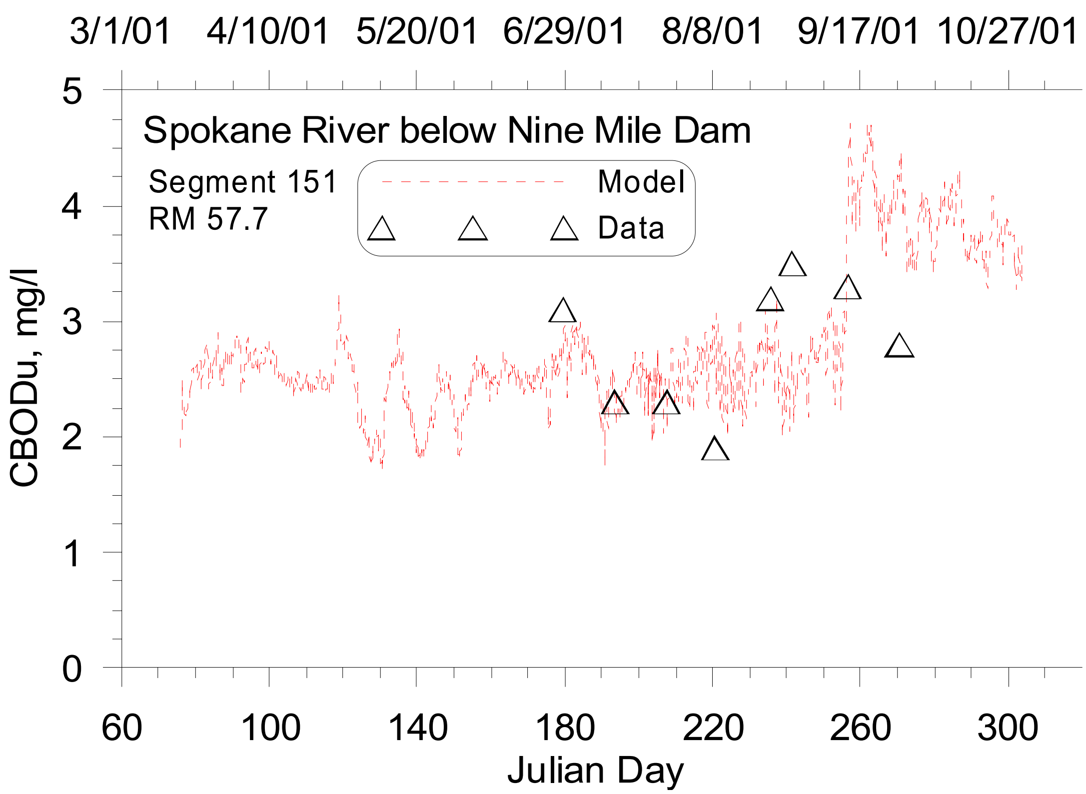

Figure 119. Comparison of model predicted CBOD ultimate and data below Nine Mile Dam

Summary

A water quality and hydrodynamic model, CE-QUAL-W2 Version 3.1 (Cole and Wells, 2001), was applied to the Spokane River from the Washington State line to the outlet of Long Lake in Washington. This model was originally calibrated to field data from the years 1991 and 2000. The calibration period was expanded in this report to include field data collected in 2001. A description of the field data used in the model and the model set-up was described in Annear et al. (2001) and Slominski et al. (2002). This report detailed the calibration of hydrodynamic, temperature and water quality variables for 2001. Model predictions were compared to field data for the following parameters:

- Water level
- Temperature
- pH
- NO_3-N+NO_2-N – nitrate + nitrite
- SRP – Soluble Reactive Phosphorus
- Chlorophyll a
- Total Nitrogen
- Ultimate Carbonaceous Biochemical Oxygen Demand
- Flow rate
- Dissolved Oxygen
- Conductivity
- NH_4-N - Ammonia
- Total Organic Carbon
- Alkalinity
- Total Kjeldahl Nitrogen
- Total Phosphorus

Field data were used in the model-data comparisons included near-surface grab sample data, continuous Hydrolab data, and vertical profiles data. Grab sample data were compared to field measurements at over 13 river-reservoir locations along the Spokane River. Vertical profiles comparisons were made at 5 Long Lake profile stations only.

In general, the model reproduces the river and reservoir responses to the known boundary conditions. Table 42 shows a summary of model errors for each parameter of interest in the Long Lake – Spokane model domain.

Table 42. Typical model errors in the Long Lake Spokane system from vertical profile and time series comparisons

Parameter	Overall Average Absolute Mean Error	Typical range in Absolute Mean Error
Water level, m	0.17	0.03 – 0.41
Flow rate, m^3/s	1.6	0.8 – 2.8
Temperature, ^oC	1.16	0.66 – 2.18
Dissolved oxygen, mg/l	1.47	0.61 – 2.05
Chlorophyll a, ug/l	0.005	0.001 – 0.017
pH	0.29	0.18 – 0.48
PO_4-P, mg/l	0.004	0.002 – 0.007
Total P, mg/l	0.008	0.004 – 0.012
Ammonia-N, mg/l	0.054	0.005 – 0.193
Nitrate-N, mg/l	0.26	0.09 – 0.52
TPN, mg/l	0.41	0.10 – 0.88
TOC, mg/l	0.86	0.35 – 2.52

The model is well suited for evaluating the impacts of management strategies to improve water quality in the Spokane River Long Lake region.

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